CONTOUR RIPPING AND COMPOSTED DAIRY MANURE FOR EROSION CONTROL ON FORT HOOD MILITARY INSTALLATION, TEXAS

A Thesis

by

LISA J. PRCIN

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2009

Major Subject: Rangeland Ecology and Management

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Approved by:

Chair of Committee,	Fred E. Smeins
Committee Members,	William E. Fox
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ABSTRACT

Contour Ripping and Composted Dairy Manure for Erosion Control on

Fort Hood Military Installation, Texas. (May 2009)

Lisa J. Prcin, B.S., Tarleton State University

Chair of Advisory Committee: Dr. Fred Smeins

Training activities on the Fort Hood Military Installation have imposed serious impacts to its grass-dominated landscape. Six decades of tracked vehicle impacts have caused soil compaction and vegetation reduction which has lead to severe surface erosion. This investigation examined two conservation practices directed at improving and creating sustainable training conditions on Fort Hood training lands, contour ripping and the application of composted dairy manure. The application of composted dairy manure may increase vegetation, while contour ripping may decrease discharge, both of which will lead to a decrease in erosion.

Three small 0.30 ha watersheds were established on Fort Hood in January 2005. Each watershed had 0.46 m berms installed on all four sides with a 0.305 m H-flume and was equipped with automated storm sampling equipment. Soil samples were collected prior to any treatments, and twice after compost applications. Discharge and precipitation was collected continuously on each watershed. Stormwater samples were collected during storm events and analyzed for water quality parameters. Water quality

samples, discharge and precipitation records were collected between January 2005 and July 2007.

Three composted dairy manure application rates at 0, 28 and 57 m^3 ha^{-1} were applied on watersheds C0, C1 and C2, respectively; watersheds were evaluated for effects on NO_3 and soluble reactive phosphates (SRP) concentrations and loadings in storm events and on stormwater discharge. Twenty two months after the initial compost application, the two previously composted watersheds (C1 and C2) were treated with contour ripping and C2 received a second compost application.

The compost application caused the spikes in NO_3 and SRP concentrations and loads immediately after application. Both NO_3 and SRP concentrations decreased as the number of days from application increased. Compost application did not appear to have an effect on the discharge from watersheds.

Contour ripping had a significant effect on stormwater discharge. Contour ripping decreased discharge by 74 and 80% on C1 and C2, respectively when compared to the untreated control (C0).

DEDICATION

This research is dedicated to the men and women serving in our military. It is my hope that the work we do on Fort Hood provides them with a sustainable landscape so that they may effectively train for combat. Thank you for all that you do to preserve the freedoms that we have as United States citizens.

ACKNOWLEDGEMENTS

This research and thesis was made possible through the efforts of many. I must thank Dr. Dennis Hoffman; I will be eternally grateful to you for allowing me the opportunity to gain experience in this field and for taking a chance on me when I knew next to nothing about rangeland re-vegetation and even less about stormwater sampling.

Dr. Fred Smeins, thank you for your support and sharing your knowledge as I analyzed and reanalyzed the data, without your assistance, this thesis would not have come to fruition. I thank my committee members, Drs. Charles Hallmark, William Fox and Dennis Hoffman for your assistance in making my thesis a better document.

I also want to extend my appreciation to Blackland Research and Extension Center, USDA – Natural Resource Conservation Service, Department of Defense – Integrated Training Area Management and Texas Water Resources Institute for providing funding for this research.

My colleagues at Blackland Research and Extension Center also deserve my gratitude for helping with the collection of storm samples and analysis, because as you know, in Texas it rarely rains, but when it does, it pours. Special thanks go to Cheryl Mannel and Loren Naylor for their help in the hot Texas sun.

I am forever grateful to my parents, Don and Lorie Barnett, for giving me every opportunity to excel and become a better person. To my husband Garrett, thank you for your unfailing support, patience and love. I am so blessed to have found you.

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INTRODUCTION

Fort Hood Military Installation opened in 1942, and in the subsequent six decades of heavy vehicle maneuver training, the landscape has become severely eroded, in part due to military training activity. The reservation encompasses 87,000 hectares of land with over 55,000 hectares dedicated to vehicular maneuver training (Fort Hood Public Affairs Office 2007) (Foster et al.). Fort Hood currently supports two armored divisions with more than 12,000 tracked and wheeled vehicles. Traffic pressures within training areas cause substantial vegetation and soil disturbance leading to increased soil movement and impairment of surrounding streams and reservoirs within and downstream of the training lands. Fort Hood's eastern boundary is located directly adjacent to Lake Belton which is the primary water supply for more than 250,000 people in the surrounding communities. Sedimentation of Lake Belton from eroding training lands has been identified as one of Fort Hood's primary environmental concerns. The Temple-Belton-Killeen area's current economic and population growth makes this water supply a precious commodity in need of protection.

Military training is intensive, recurring, and involves many soldiers, armored vehicles and ordinances. Thus, military activities can adversely affect natural resources at both short and long-term scales, through removal of vegetation, soil compaction,

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This thesis follows the style of *Rangeland Ecology and Management*.

erosion and rutting (Svendsen et al. 2006). A 1996 Department of Defense (Department of Defense (DoD)) policy requires the military to maintain and improve the sustainability and native biological diversity of terrestrial and aquatic ecosystems while supporting human needs, including military training . In short, DoD must strive to be good stewards of the land while allowing for necessary military mission training.

In conjunction with the United States Department of Agriculture - Natural Resources Conservation Service (Natural Resource Conservation Service (NRCS)), Fort Hood has developed many Best Management Practices (BMPs) in an effort to reduce erosion from the military installation and subsequent deposition and siltation of surrounding lakes and rivers. Successful BMPs include sediment retention structures to trap sediment and contour ripping in conjunction with a system of gully plugs (Military Access Structures or MASs) to increase infiltration, slow gully formation and trap sediment. While these BMPs are effective for slowing sediment loss, they are not easily sustained. Each treatment has a life expectancy of operating at optimal capacity, and once that lifespan has been reached, their effectiveness decreases and the process must begin anew.

There is a need for sustainable practices that enable the landscape to mend itself after training maneuvers. Revegetation efforts on military training lands must be self-sustainable after the first or second growing season with no additional inputs. To achieve this goal, erosion must be under control, natural nutrient cycles must be reinitiated and selected species must be adapted to the present site conditions (Anderson and Ostler 2002). Healthy ecosystems have the ability to repair themselves after damage. Once the damage is greater than the ecosystems self-repair threshold, the landscape loses that ability and cannot naturally repair the damage (Whisenant 1999). A healthy plant community may be the answer to restore the natural ability to self-repair. Land managers are currently developing re-vegetation BMPs with the use of composted dairy manure alone and with contour ripping applications. Additions of composted dairy manure may return nutrients and organic matter that have been lost from the soil over time, both of which are necessary for a healthy plant community.

While large scale applications of compost are difficult and costly, there is the possibility that when used in conjunction with contour ripping, it may be a more feasible option. The contour rips provide a prepared seedbed in which the addition of compost and seed can be applied. Contour ripping may also use to increase infiltration in compacted soils (Anderson and Ostler 2002).

There is an added benefit to the use of composted dairy manure to aid in re-vegetation and control erosion. The military installation is located adjacent to the Bosque River Watershed, which is listed by Texas Commission on Environmental Quality's (TCEQ 2007) as having impaired water quality due to excessive nutrients. High nutrient levels can cause excess growth of algae, in turn causing taste and odor problems in drinking water (King et al. 2007). Export of composted dairy manure from the Bosque River Watershed may reduce the nutrients loads within the impaired watershed.

OBJECTIVES

Contour ripping and compost application are expensive land treatments. Much of the literature about the effects of ripping has been done in the arid western United States. An evaluation of the effectiveness of contour ripping, specific to Fort Hood's climate and landscape is needed for land managers to make informed decisions.

Compost application has been investigated as a possible BMP to re-vegetate training areas. Fort Hood has determined two application rates that appear to create the best vegetation response. While these rates appear to help the vegetation community, it is necessary to determine if there are possible adverse affects on water quality associated either of these two rates.

This research included two objectives: 1) to quantify the effect of contour ripping on stormwater runoff discharge and 2) to quantify the effects of two different composted dairy manure application rates on stormwater runoff quality. The stormwater discharge aspect of the study tested the hypothesis that areas with contour ripping would have the same stormwater runoff discharge as an area without contour ripping. The water quality aspect of the study tested the hypothesis that there would be no difference in the amount of nitrate and soluble reactive phosphate (SRP) in the stormwater runoff from plots treated with no compost and with compost at rates of 28 m^3 ha^{-1} and 57 m^3 ha^{-1}. These two objectives were carried out concurrently on three small bermed and instrumented watersheds located on Fort Hood.

LITERATURE REVIEW

Effects of Military Training on the Landscape

The United States Army oversees more than 4.8 million ha of federally owned land, which must be managed sustainably to promote realistic and safe combat training (Anderson et al. 2005). Effects of military training on the landscape are well documented (Shaw and Diersing 1990; Trumbull et al. 1994; Milchunas et al. 2000; Grantham et al. 2001; Quist et al. 2003; Palazzo et al. 2005; Foster et al. 2006; Svendsen et al. 2006; Althoff et al. 2007; Dickson et al. 2008).

Necessary repetitious training regimes disaggregates and compacts soils (Palazzo et al. 2005). Although vehicles are a more obvious source of compaction, Trumbull et al. (1994) found that disturbances caused by military campsites also had lower infiltration rates when compared to unused sites indicating compacted soils. Compacted soils result in lower infiltration rates and more runoff during low to moderate intensity storm events (Althoff et al. 2007). Compacted soils also reduce plant root penetration and resilience of desired species (Milchunas et al. 2000; Palazzo et al. 2005).

Off-road military vehicles cause areas devoid of vegetation and create gullies, which promote soil movement into the surrounding waterways, causing impairment of streams within and downstream of the training sector (Palazzo et al. 2005; Svendsen et al. 2006; Althoff et al. 2007). Military traffic also causes changes in proportions of vegetation, bare ground and litter cover (Milchunas et al. 2000). The composition of the plant community is altered by the training traffic. Replacement of perennials by annuals, increased potential of exotic species invasions(Milchunas et al. 2000), and declines in the biomass of native species (Palazzo et al. 2005) are all effects of military training. All of these changes to the landscape and ecosystems result in reducing the quantity and quality of lands available for training and wildlife habitat (Althoff et al. 2007).

While there is an abundance of literature available describing the effects of military training, there is little available concerning the re-vegetation and rehabilitation specific to military training lands. These are both necessary to continue long-term training and maintain good stewardship of the land.

Composted Dairy Manure and Runoff Quality

Erosion of the landscape results in the loss of nutrient-rich topsoil. Composted dairy manure as a soil amendment may have both short and long term benefits. In the short term, application of compost may improve soil surface protection from raindrop impact and subsequent disaggregation (Kleinman et al. 2002; McDowell and Sharpley 2003). This would be especially true with higher application rates which would create a thicker compost layer on the soil surface.

Compost application on degraded landscapes can have advantageous benefits on soil physical and chemical properties. Compost is an available source of nutrients and organic matter. The addition of compost may increase soil organic matter levels which affects porosity, aggregate stability, infiltration and soil fertility. All are factors which affect runoff, erosion potential, and water retention capacities of the soil (Kleinman et al. 2002; Meyer et al. 2004; Claassen and Carey 2007).These benefits may then result in increased vegetation and in turn, decreased storm water runoff.

For all the possible benefits compost application may have, for both ecological and economical reasons, it is imperative that the proper rate be used. Too little compost applied will have no measurable effects on vegetation and soil physical and chemical characteristics, but too much applied is both costly and wasteful of excess nutrients which may end up downstream. The loss of nutrients may occur when compost is applied to soil, resulting in environmental pollution. Loss of nutrients can cause adverse implications to the surrounding water supply. Diffuse loading of phosphorus (P) and nitrogen (N) in surface waters have be linked as drivers that cause increases in the trophic status of lakes or eutrophication, streams and rivers (Kleinman et al. 20032004). Eutrophication has serious impacts on both the aquatic ecology level and on municipal resources. Eutrophication and the subsequent increased algae production reduces diversity of flora and fauna, causes changes in the dominant biota, as well as fish kills when the algae dies. Eutrophication of surface waters also increase the cost of water treatment for municipalities and decrease the recreation value of fresh waters (Kleinman and Sharpley 2003; Burke et al. 2004; Elliott et al. 2005). More focus is being placed on the effects of increased P and N concentrations in streams and lakes (Eghball and Gilley 1999). In 1998, the United States Environmental Protection Agency (EPA) identified phosphorus as the most wide spread water nutrient that contributed to eutrophication of water bodies (Kleinman and Sharpley 2003).

EPA requires drinking water to be below 10 mg l^{-1} NO_3-N, and this number has become a reference point for aquatic systems, even those not used for drinking water. EPA requires streams which do not discharge directly into lakes to not exceed 100 μg l^{-1}

of SRP. At the state level, TCEQ developed freshwater stream screening levels for nutrients. These screening levels are designed to protect general water quality concerns, rather than directed towards a specific threat. TCEQ requires that freshwater streams not exceed thresholds of 2.76 mg l^{-1} and 500 μg l^{-1} of NO_3-N and SRP, respectively (King et al. 2007). Nitrate-N is the plant available anionic form of N in soils and is soluble and mobile in soils and easily leached during storm event (Miller and Donahue 1995). SRP is the inorganic form that is the most readily plant and algal- available P form and therefore used as an environmental indicator (Burke et al. 2004).

There are three primary factors that control the potential for transport of nitrogen and phosphorus in composted dairy manure from the land to which it was applied; timing of application, application method and rate (Sharpley 1997). Studies have found that generally the bulk of N and P losses occurred during the first one or two intense storms. As the amount of time between application and surface runoff event increases, the concentration of N and P in runoff decreases. Immediately following broadcasting the potential for P loss peaks and then declines over time, as water soluble P applied in the manure increasingly interacts with soil and becomes more and more recalcitrant. Over time, the applied nitrogen is reduced by the formation of NO_3-N and subsequent movement through the soil profile and volatilization of NH_3. Phosphorus is conserved in the compost-soil mix by sorption processes, thus the decrease in phosphorus available for transport with time after application can be a function of soil type and phosphorus sorption saturation. So, the time between application and runoff will have a greater influence on phosphorus concentration of runoff from soils with higher rather than lower phosphorus-sorbing soils (Sharpley 1997). Studies by Mueller et al. (1984) reported SRP concentrations declining from 0.94 to 0.26 mg l^{-1} in runoff within two months of the growing season from no-till plots that received broadcast application of dairy manure. Another study by Gascho et al. (1998) reported declines of SRP concentrations from >5.0 to <1.0 mg l^{-1} from a field receiving mineral fertilizer application in a slightly shorter time period. In a rainfall simulation study utilizing indoor runoff boxes, Kleinman and Sharpley (2003) found that treatments with over 50 kg total phosphorus (TP) ha^{-1} applied, the number of days between manure application and runoff event was negatively related to SRP.

The method of compost application also plays a role in the potential for nutrient loss in subsequent runoff events. Surface or broadcast application concentrates the nutrient source at the top of the soil, where it is most vulnerable to runoff. Eghball and Gilley (1999) conducted a study comparing the runoff concentrations from wheat and sorghum fields receiving broadcast compost treatment or compost which had been incorporated. They reported in the wheat fields with no incorporation, the dissolved phosphorus and NH_4-N were significantly greater during simulated rainfall runs.

Manure application rate also regulates the concentration of P available to runoff water at the soil surface (Kleinman and Sharpley 2003). Kleinman and Sharpley (2003) compared runoff concentrations of indoor runoff boxes with varying rates of compost applied. Application rates were related to runoff P (r^2 = 0.50-0.98). As the application rates increased, so did the contribution of soluble reactive phosphate.

Alternatively, in rainfall simulations conducted on a post forest fire landscape, Meyer et al. (2001) found that mean total runoff concentrations of nitrite-N (NO_2-N) and NO_3-N did not increase with increasing application biosolid rates, nor were there consistent trends over time within and between biosolids rates in the concentrations of NO_3-N, NH_4-N or Total Kjeldahl N (TKN). Sediment concentration was also significantly reduced in treatments of 40 Mg ha^{-1} and 80 Mg ha^{-1} when compared to sediment concentration on the control plots. Compost application rates did not affect mean total runoff (Meyer et al. 2001).

While there is a multitude of data available about runoff water quality following compost or biosolids application, it typically is done on croplands, forestlands or bare soil simulations. There is a lack of literature concerning the applications to rangeland settings. There is a need for further evaluation to determine the proper rate for best success in re-vegetating disturbed rangelands without impairing the surrounding water supply.

Contour Ripping and Stormwater Discharge

Mechanical rangeland treatments may be another possible alternative to alleviate the effects of intensive military training on the landscape. Ripping the landscape along contour lines, a practice known as contour ripping, to breakup compacted soils and encourage infiltration was a popular management practice on western rangelands throughout the early to mid 1900’s. Between 1934 and 1940, one-million plus acres received contour ripping treatments (Branson et al. 1966). Typically, contour ripping is accomplished with a chisel or shank attached to a bulldozer or tractor, which creates a furrow or "rip" in the surface horizon of the soil.

Soil moisture is a common limiting factor in rangeland ecosystems and any practice that increases soil moisture maybe beneficial for re-vegetation and biomass production (Gade 2006). Contour ripping can increase infiltration by creating small storage for precipitation and slowing overland runoff by roughening and loosening the soil surface (Branson et al. 1966; Griffith et al. 1984; Gade 2006).

Contour ripping is an ideal management tool in rangelands with dense, fine textured soil, such as clays, that have low infiltration rates. Soils that are heavily compacted by livestock or vehicle tracks can also benefit from contour ripping. Rangelands with dense sod-bound areas can yield more than twice the amount of runoff than rangelands with healthy bunch grass communities, and may also benefit from contour ripping treatments. Rangelands with high percentages of bare soil exposed may also benefit from contour ripping treatments to increase infiltration and decrease soil loss by overland flow (Gade 2006).

Contour ripping can increase biomass production through the disturbance of native sod and shift the botanical composition to more productive species. The increase in infiltration, creation of more open spaces for productive species and reduced competition from unwanted vegetation also encourages further establishment of desired vegetation, provided the desired species were present in sufficient quantities pre-treatment to make use of this advantage (Griffith et al. 1984; Miyamoto et al. 2004; Gade 2006).

STUDY AREA

Fort Hood (87,953 ha) is located in Central Texas and encompasses parts of western Bell and eastern Coryell counties (Fig. 1). It is located 80 km southwest of Waco, TX and 96 km north of Austin, TX. Elevation ranges from 180 to 375 m above sea level with 90% of the installation below 260 m (Anderson et al. 2005). The primary heavy vehicle training areas are located in Coryell County, which consists of an undulating dissected limestone plain underlain by softer limestone and marly clay on the rolling hills and plateaus and hard limestone on the higher ridges. Soils are generally described as shallow to moderately deep, clayey and underlain by limestone bedrock. Slopes are between 2% to 5% with some exceeding 45% along flood plain bluffs and side slopes of mesa hills (McCaleb 1985). The three experimental watersheds are located in close proximity to each other on a Cho clay loam soil.

Fort Hood's climate is characterized by hot summers and mild winters (Fig. 2). In the winter, the average temperature is 9.4°C with an average daily minimum temperature of 2.2°C. During the summer, the average temperature is 28.3°C, with an average daily maximum of 35.5°C in July. Precipitation is somewhat uniformly distributed throughout the year, with slight peaks in the spring and fall and droughty conditions in mid- to late summer. Of the annual total of 86.4 cm of precipitation, 55% usually falls between April and September (McCaleb 1985), however, great seasonal and annual variation in amount and distribution occurs.

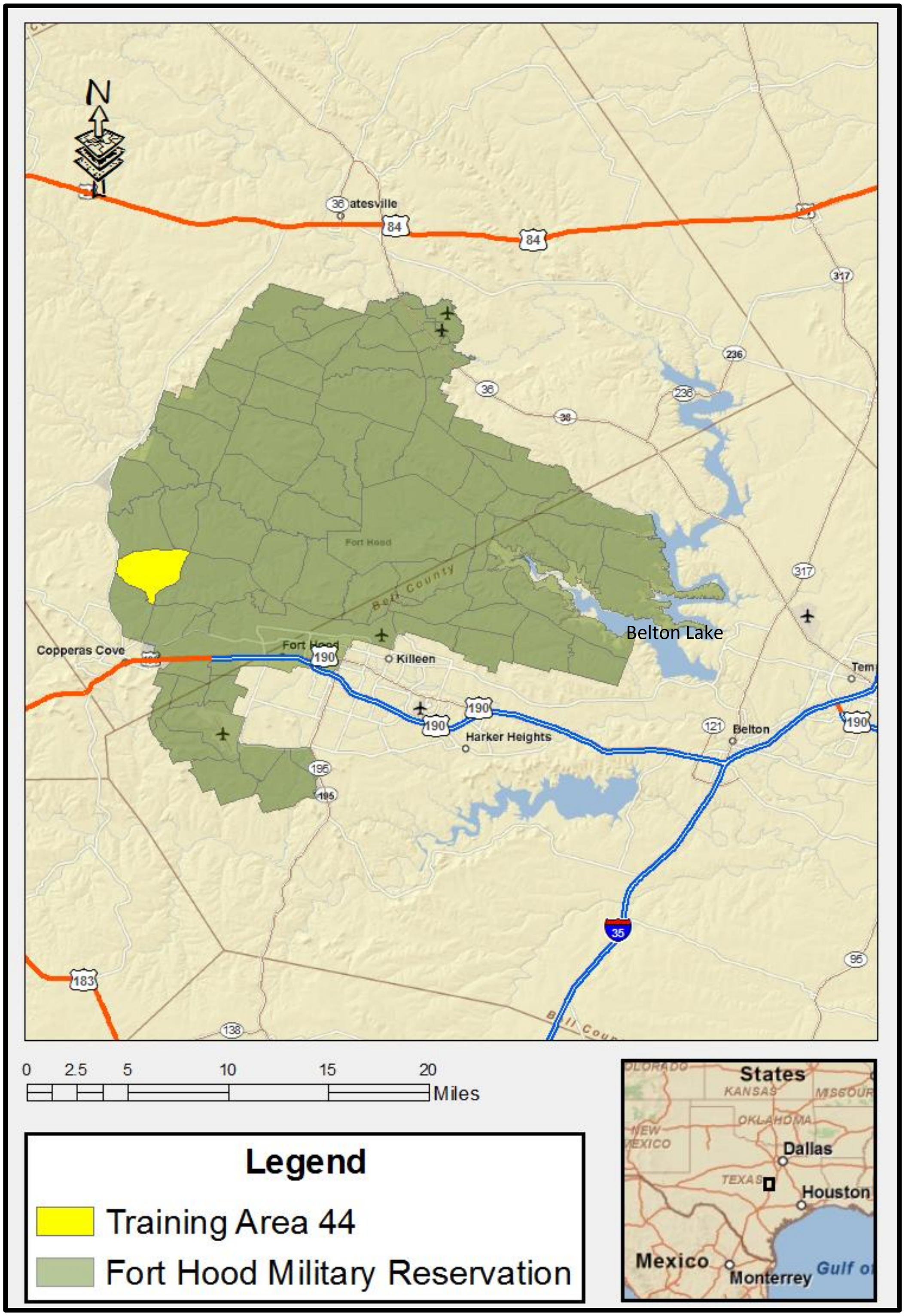

Figure 1 Fort Hood Military Reservation is located in Coryell and Bell counties, approximately 96 km north of Austin, Texas. Most of the primary training areas discharge into the adjacent Belton Lake reservoir. Research was conducted within Training Area (TA) 44.

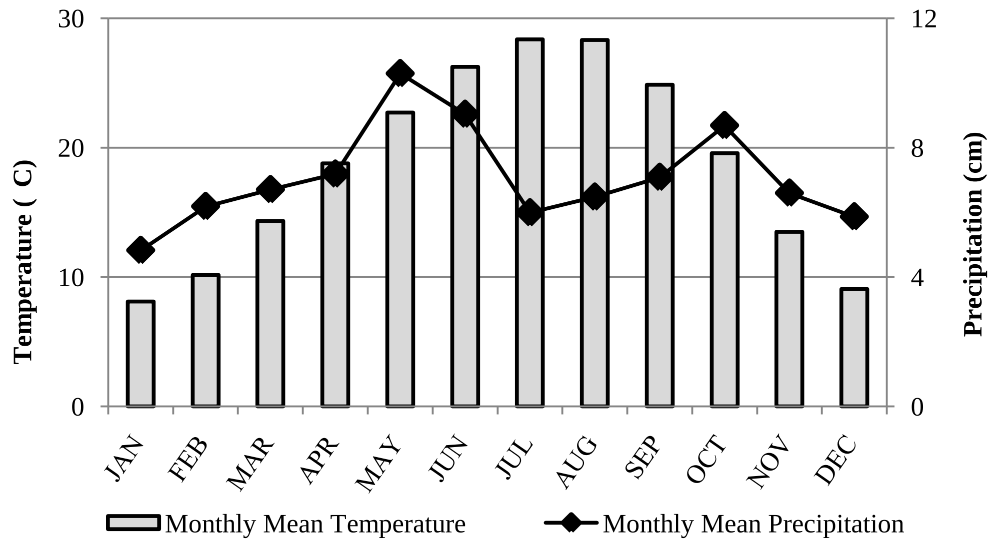

Figure 2 Historical monthly average temperature (°C) and monthly average precipitation recorded by NOAA at Gatesville (ID 4 SSE) weather station from 1968 – 2006.

Fort Hood lies within the Lampasas Cut Plain eco-region and is typically composed of oak woodlands with a grassland understory. Woody vegetation consists of Ashe juniper (*Juniper ashei* J. Buchholz), live oak (*Quercus virginiana* P. Miller var. fusiformis (J.K. Small) C. Sargent) and Texas oak (*Quercus buckleyi* Nixon & Dorr). The climax grass community consists of little bluestem (*Schizachyrium scoparuim* (Michz.) Nash) and yellow Indian grass (*Sorghastrum nutans* (L.) Nash) (Gould 1975). All nomenclature follows Vascular Plants of Texas by Jones et al (Jones et al. 1997).

Due to the continual disturbance caused by military training, much of the area is dominated by lower successional plants, including many annual species. In addition, the exotic King Ranch bluestem (*Bothriochloa ischaemum* (L.) songarica (Fisch. & Mey.)) is wide spread and dominates large areas. Areas of intense training have a high percentage of bare soil along with many ruts and large depressions covering the soil surface.

Fort Hood has a free range grazing system and study areas were lightly to moderately grazed during some of the study period. While prescribed burning is used as a management tool by Fort Hood land managers, the study area had not been treated in recent years. The study area was also closed to military training during the study period as a part of a rotational training area “rest” program.

EFFECTS OF COMPOST APPLICATION AND CONTOUR RIPPING ON STORMWATER RUNOFF QUALITY AND DISCHARGE

This research investigated two hypothesis, 1) watersheds that have been contour ripped will have similar amounts of discharge as a control watershed with no contour ripping, and 2) watersheds with two different application rates of composted dairy manure will have no significant differences in water quality, specifically, NO_3 and SRP load and concentration. These two objectives were carried out concurrently on three small bermed and instrumented watersheds located on Fort Hood. Research watersheds were designed and maintained by personnel from Blackland Research and Extension Center –Texas AgriLife Research (Althoff et al.) in Temple, TX.

MATERIALS AND METHODS

Experimental and Treatment Design

Three experimental watersheds (45 m X 67 m) were established in TA 44 to investigate the effects of contour ripping with stormwater discharge and compost application rate on stormwater quality (Fig. 3). Due to equipment constraints, this was a non replicated study. Watersheds were located approximately 6.5 km north of Copperas Cove in Coryell County. All watersheds were within 150 m of each other and were located on Cho clay loam, which are Loamy, carbonatic, thermic, shallow Petrocalcic Calciustolls formed in calcareous, loamy sediment with a 1-3% slope. The Cho series consists of very shallow and shallow well drained loamy soils found on uplands (McCaleb 1985).

In January 2005, all vegetation was shredded and left on the ground, and 0.46 m high earthen berms were installed on all four sides of each plot (Fig. 4A). A 0.305 m H-flume was installed at the drainage point of each watershed to provide a fixed monitoring point for accurate flow measurements (Fig. 4B).

Watersheds were equipped with an ISCO 4230 Bubble Flow Meter (Teledyne Isco Inc, Lincoln, NE) to measure and record level and flow at one-minute intervals. An ISCO 3700 Automated Sampler was used to collect runoff samples during storm events. A Texas Electronics TX-25 tipping bucket rain gauge (Texas Electronics, Dallas, TX) was used to measure precipitation to one-hundredth of an inch. Power was supplied with a 10 watt solar panel and a marine deep cycle battery. Sampling and monitoring stations were visited and maintained every 10-14 days to ensure proper functioning of all equipment.

In January 2005, two different rates of compost were randomly applied to two of the micro-watersheds (C1 and C2), while the third remained an untreated control (C0) (Figs. 3 and 4C – D). Compost was broadcasted at rate of 28 m^3 ha^{-1} on C1 and 57 m^3 ha^{-1} on C2. These rates applied 74 and 151 kg of nitrogen, and 43 and 86 kg of phosphorus to C1 and C2, respectively (Table 1). Nutrient application rates were based an analysis of nutrient content of composted dairy manure from within the Bosque River watershed determined by Texas AgriLife Extension Soil, Water and Forage Testing Laboratory in College Station, Texas.

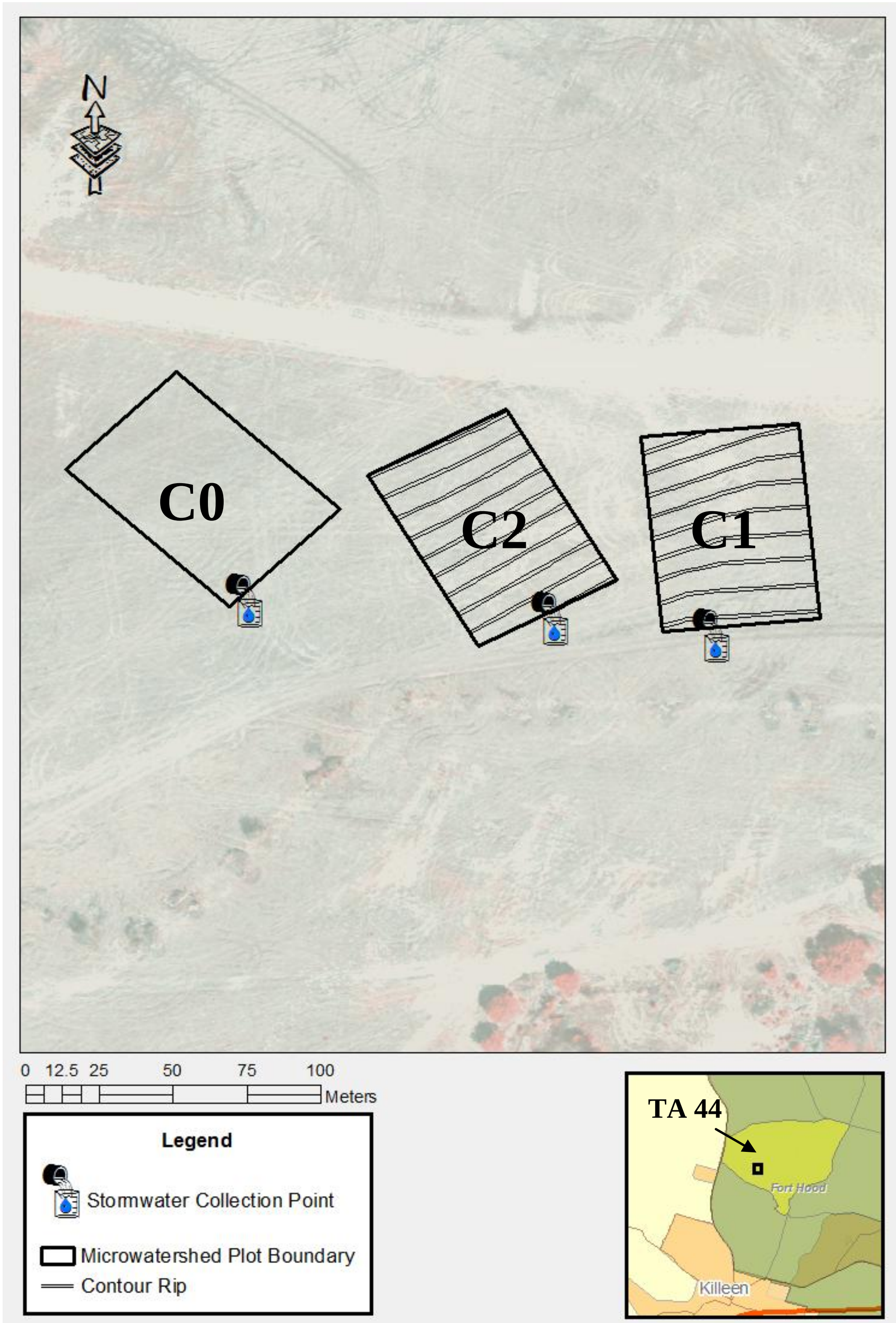

Figure 3 Research watersheds were located in Training Area (TA) 44. Three watersheds (45 m x 67 m) were bermed and implemented to measure stormwater discharge and quality. Watershed C0 received no treatment while C1 and C2 received compost applications and contour ripping.

Table 1 Application rates of composted dairy manure for each treatment per hectare and per plot with corresponding application rates of nitrogen and phosphorus.

Treatment	Per Hectare			Per Watershed		
ID	Rate	N	P	Rate	N	P
	--$m^3{\cdot}ha^{-1}$--	----- $kg{\cdot}ha^{-1}$ -----		--m^3--	------- kg -------	
C1	0	0	0	0	0	0
C1	28	243	142	8	74	43
C2	57	497	285	17	151	86

Compost was applied with a custom-built High Roller compost spreader (Texas High Roller, Bryan, TX), designed specifically for use on the Fort Hood terrain, pulled by a John Deere 4430 tractor. The spreader has a capacity of 11.5 m^3 and was calibrated every 4 to 5 loads to ensure accurate application rate. Calibration was done by determining the amount of compost delivered when making one pass over a one square-meter tarp. A minimum of three passes were made, then averaged and extrapolated to the desired amount per hectare.

After compost application, a native seed mix developed by BREC/ NRCS (Table 2) was applied with a Herd Sure-Feed broadcast seeder (Herd Seeder Company Inc, Logansport, IN) mounted on the back of an ATV. The seed mix included eleven native grass and forb species and was applied at 7.85 kg ha^{-1}.

In November 2006, the two previously composted watersheds, C1 and C2, received contour ripping treatments. Watershed C2, originally treated with rate of 57 m^3 ha^{-1}, received an additional 28 m^3 ha^{-1} of compost. Compost was applied in the same manner used for the original application.

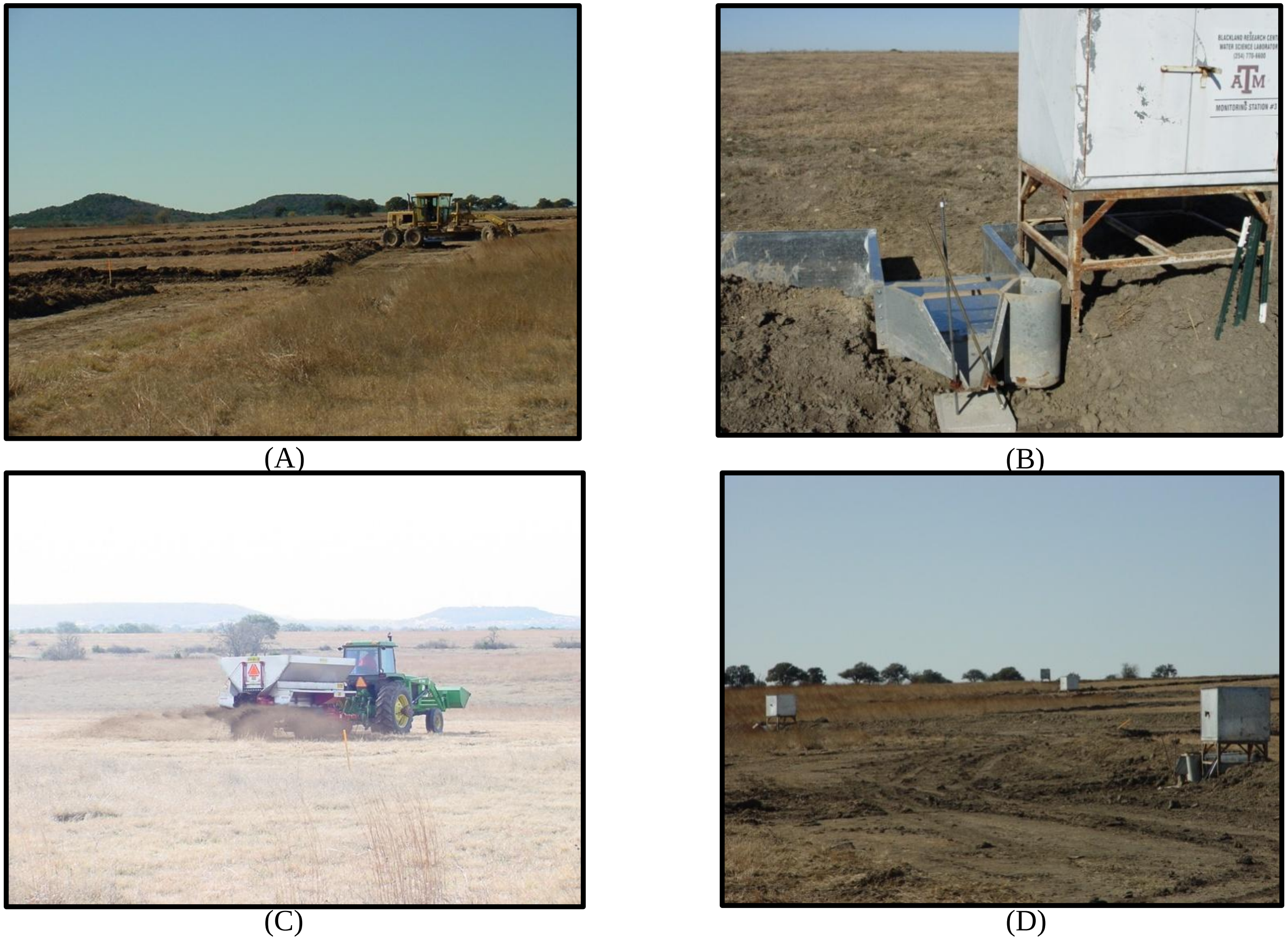

Figure 4 Establishment of experimental watersheds took place in December 2004 to January 2005. A) Watersheds were mowed and 0.46 m high berms were built, B) One-foot H-flumes were installed along with sampling equipment on each watershed, C) Composted dairy manure was applied to two watersheds (C1 and C2) at different application rates, D) View of watershed sampling points.

Table 2 Composition of native species in BREC/NRCS seed mix.

Scientific Name	Common Name	Cultivar	Percentage of Mix
Bouteloua curtipendula	sideoats grama	Haskell	25%
Buchloe dactyloides	buffalo grass	Texoka	25%
Andropogon gerardii	big bluestem	Earl	10%
Panicum virgatum	Switchgrass	Alamo	10%
Schizachyrium scoparium	little bluestem	Native	10%
Sorghastrum nutans	yellow Indiangrass	Lometa	10%
Sporobolus compositus	tall dropseed	Native	5%
Desmanthus illinoensis	Illinois bundle-flower	Sabine	2%
Simsia calva	awnless bush-sunflower	Plateau	2%
Chamaecrista fasciculata	partridge-pea	Lark	1%
Leptochloa dubia	green sprangletop	Van Horn	1 lb/acre

Contour ripping of C1 and C2 was done following NRCS specifications set in the NRCS Field Office Technical Guide for Coryell County (NRCS 2008) by an NRCS selected contractor. Contour ripping treatment consisted of fracturing compacted soil layers on 3 m intervals with a bulldozer with a single ripping shank attached directly behind the tracks of the bulldozer (Fig. 5A, 5B). The shank was approximately 8 cm wide and ripped the soil to an average depth of 38 cm. The watersheds were ripped parallel to surveyed contour lines.

Sampling and Analysis

Prior to any treatments, soil samples were collected from the watersheds. Each sample was a composite of six random subsamples per watershed. Samples were collected from two different soil depths, 0 to 5 cm and 5 to 15 cm. All samples were air-dried and sent to Texas AgriLife Extension Soil, Water and Forage Testing Laboratory

(A) (B)

(C) (D)

Figure 5 Application of contour ripping treatments. A, Bulldozer used in contour ripping. B, Close-up of ripping shank used in contour ripping. C, View of watershed after contour ripping treatment. D, Close-up of furrow created by contour ripping treatment.

in College Station, Texas for analysis. Additional soil samples were collected 15 and 22 months post compost application using the same methods as previous samples. Samples were analyzed for pH, conductivity, nitrate-N, phosphorus, potassium, calcium, magnesium, sulfur and sodium content. Samples collected in December 2004 were also analyzed for organic matter content.

Stormwater discharge and precipitation records for all three watersheds began 26 January 2005, prior to the any storm events. Water quality samples and measurements were not collected for C1 and C2 until compost and seed treatments had been applied. Watershed C1 received a compost application on 26 January 2005. Five successive rainfall events occurred within eleven days following application. C2 watershed was treated three weeks later, on 13 February 2005 because of prolonged period of rainfall. Storm events began ten days after compost treatment on C2. Stormwater discharge, precipitation and water quality data were collected until July 2007.

The study period was divided into two periods for the stormwater discharge aspect. Precipitation and discharge data collected from January 2005 through October 2006 is categorized as the calibration or pre-rip period. Storm events monitored from November 2006 through July 2007 were categorized as the treatment or post-rip period.

Surface stormwater discharge was measured by the total volume of stormwater that passed through the H-flume in a storm event from time of the first rise in level until the flow returned to zero. Since the parameter of interest was total discharge and percent runoff, all measured flow was used in determinations. C1 and C2 had periods of interrupted precipitation data, however C0, had complete records, so precipitation data from C0 was used in runoff percent calculations. Precipitation was assumed to be homogenous across all watersheds. Discharge was defined as the total volume through the monitoring point for each event and is reported as millimeters of discharge. Percent runoff was calculated by dividing total discharge by total precipitation for each event.

In periods of extended precipitation (two or more consecutive days with runoff producing precipitation), precipitation and discharge volumes were summed and reported as one event. After soil had reached its full water holding capacity, antecedent soil moisture conditions controlled discharge rather than the amount of precipitation on that calendar day.

Storm event sampling for water quality analysis occurred when the water level in H-Flume reached 32 mm, the depth necessary to submerge the sample intake line. Only flows above this level were used in determination of nutrient loads and event mean concentration. The automated sampling equipment collected one discrete, time-based sample every 30 minutes after the level threshold had been surpassed and continued until the level returned to below the threshold. A total of 24 individual samples were possible for each event from each watershed.

For most storm events, three samples were analyzed from each watershed. Samples were collected at the beginning of the event, near the peak and half way down the descending limb of the hydrograph. The runoff hydrograph, from individual storms, was divided into sections representing the time interval during which the sample was collected (Fig. 6).

At times, this wasn't possible and some events had greater or less than three samples collected and analyzed. Samples were taken to the Water Sciences Laboratory at Blackland Research & Extension Center and analyzed for NO_3^- (NO_3) and PO_4^{3-} (SRP) content with Standard Method 4110 C, single-column ion chromatography with direct conductivity detection (Eaton et al. 2005).

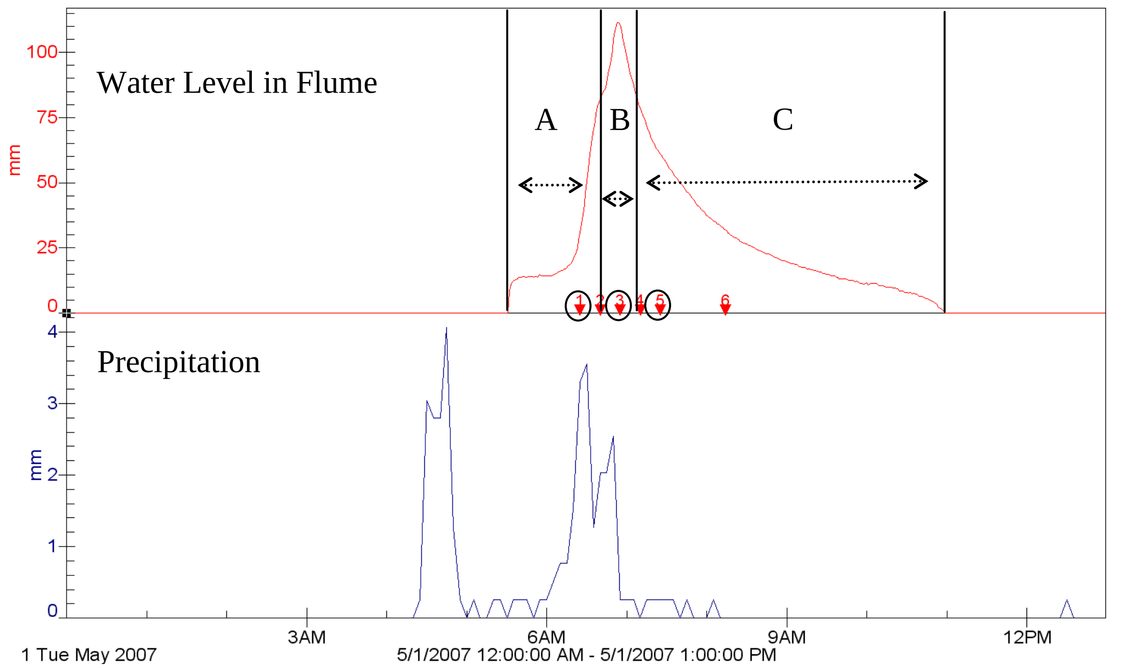

Figure 6 Example of a storm hydrograph depicted in FlowLink software (Teledyne Isco, Inc.) showing stormwater level (depth) in flume and precipitation. Samples collected are represented with numbered triangles and samples analyzed are circled. Measured concentration of each sample is associated with the flow volume for its associated time interval.

Use of watersheds created an edge-of-field scenario. Nutrient transport from these watersheds was a function of precipitation. The transport of most water quality constituents is typically described in terms of loading and event concentration. Loads are a function of constituent concentrations and storm water volume (Toor et al. 2008).

This sampling strategy was adapted from the rise-fall low frequency sampling strategy utilized by Toor et al (2008). To calculate storm load, sample concentrations were then multiplied by the runoff volumes for each representative time interval to determine the mass of NO_3 and SRP. To estimate mean event concentration, measured sample concentrations were multiplied by the associated flow volume, summed and then divided by the total flow volume for the event,

$$\boldsymbol{EMC} = \frac{(C_1 \times Q_1) + (C_2 \times Q_2) + \ldots (C_n \times Q_n)}{Q_1 + Q_2 + \ldots Q_n} \qquad \textbf{[1]}$$

where EMC is event mean concentration, C is the concentration of specified sample and Q is discharge for the associated time interval. Concentration was reported in milligrams per liter.

Statistical Analysis

Since there was only one replicate of each treatment and the data were not normally distributed, non-parametric tests were used for statistical comparisons. For the stormwater discharge study, differences within a watershed over pre- and post- rip periods were first investigated with the Friedman test, and then further analyzed with the Mann-Whitney test. Treatment comparisons within the pre- or post- rip periods were made with the Wilcoxon Signed Ranks test. Precipitation differences between the two periods were investigated with the Kruskal Wallis test.

The stormwater quality study was divided into individual years and also compared as an entire study period (January 2005 to July 2007). Differences in NO_3 and

SRP concentrations and loads between treatments within an individual year were determined with the Wilcoxon Signed Ranks test.

All results were considered significant at $p < 0.05$. The Mann-Whitney and Wilcoxon Signed Ranks tests do not make assumptions about homogeneity of variances or normal distributions. They are slightly less powerful than a t-test or one-way ANOVA, and therefore less likely to find a significant result when there is no difference (Dytham 2003).

Collected soil samples were not replicated, so only general descriptive statistical comparisons between treatments and over time were made.

All statistical analysis were made with SPSS statistical software package (SPSS Inc. 2006).

RESULTS

Soils

Detailed soils analysis for the three sample dates are presented in Table 3. Soils analyses were done to determine the impact of compost applications on soil chemical characteristics. Specifically, nitrate-N and phosphorus were used to determine if compost application caused an increase in soil nutrient levels.

Table 3 Analysis of soil samples collected from C0, C1 and C2 watersheds in December 2004, March 2006 and November 2007. Soil samples were collected from at soil depths, 0 to 5 cm and 5 to 15 cm. Soil samples were analyzed by the Texas AgriLife Extension Soil, Water and Forage Testing Laboratory in College Station, Texas.

Date	Watershed	Depth	pH	Conductivity	Nitrate-N	Phosphorus	Potassium	Calcium	Magnesium	Sulfur	Sodium	Organic Matter
				--umho cm^{-1}--	--ppm--	--ppm--	--ppm--	--ppm--	--ppm--	--ppm--	--ppm--	%
December 2004 -- Pretreatment												
	C0	0 - 5 cm	8.2	217	11	5	294	18,587	184	26	198	5.87
	C0	5 - 15 cm	8.2	212	2	2	199	31,312	171	32	250	4.07
	C1	0 - 5 cm	8.2	237	11	2	192	32,739	158	28	236	5.68
	C1	5 - 15 cm	8.5	104	3	1	172	38,736	156	28	248	3.75
	C2	0 - 5 cm	8.0	258	25	4	192	32,404	157	32	229	5.73
	C2	5 - 15 cm	8.7	92	4	1	116	41,569	139	27	218	3.88
March 2006 (15 months post initial compost application)												
	C0	0 - 5 cm	8.1	259	4	11	350	14,669	174	21	189	NA†
	C0	5 - 15 cm	8.1	155	3	6	278	16,594	153	18	173	NA
	C1	0 - 5 cm	8.2	148	3	17	256	18,969	179	21	178	NA
	C1	5 - 15 cm	8.3	218	3	8	187	18,925	122	18	176	NA
	C2	0 - 5 cm	8.0	150	3	31	301	24,156	213	28	191	NA
	C2	5 - 15 cm	8.3	142	3	12	219	24,473	160	26	193	NA
November 2006 (22 months post initial compost application)												
	C0	0 - 5 cm	8.2	177	3	10	305	13,278	155	20	88	NA
	C0	5 - 15 cm	8.3	201	1	9	253	15,118	143	21	128	NA
	C1	0 - 5 cm	8.1	239	1	25	253	13,858	167	19	110	NA
	C1	5 - 15 cm	8.3	160	1	10	187	17,485	139	22	96	NA
	C2	0 - 5 cm	8.1	212	2	20	232	15,973	173	23	85	NA
	C2	5 - 15 cm	8.5	155	1	10	134	18,204	117	21	120	NA

† Organic matter was not analyzed in samples collected in March and November 2006

In December 2004, prior to any treatments, soil samples from C0 and C1 watersheds both had 11 ppm of NO_3-N in the 0 to 5 cm depth, while C2 had 25 ppm NO_3-N, two times the amount of N than C0 and C1 watersheds (Figs. 7A and 7B). This trend did not continue in the deeper sampling depth; all three watersheds ranged from 2 to 4 ppm NO_3-N in the 5 – 15 cm soil depth. Available phosphorus (P) at both 0 – 5 cm and 5 – 15 cm depths were very similar in all three watersheds, ranging from 2 to 5 ppm P in the 0 to 5 depth and 1 to 2 ppm P in the 5 to 15 cm depth for all three watersheds (Figs. 7C and 7D).

A second composite soil sample was collected from each watershed 15 months after the original compost applications in March 2006. Nitrate-N levels decreased in all watersheds at both sampling depths from December 2004. Measurements ranged from 3 to 4 ppm NO_3-N for samples collected in the 0 to 5 cm depth and all three watersheds had 3 ppm NO_3-N in the 5 to 15 cm sampling depths (Fig. 7A and 7B).

Alternatively, available P was elevated when compared to the pre compost application samples collected in December 2004. Although available P content in C0 watershed was only slightly elevated when compared to early samples in the 0 – 5 cm depth, C1 and C2 had much higher available P levels. Available P in C1 increased from 2 ppm P in December 2004 to 17 ppm P in March 2006. Available P level in C2 increased from 4 ppm P in December 2004 to 31 ppm P in March 2006 (Fig. 7C).

This same trend was also expressed in the samples collected at 5 to 15 cm sampling depth, but with a lower magnitude of difference, with C1 increasing from 1 ppm P to 8 ppm P, while C2 increased from 1 ppm P to 12 ppm P (Fig. 7D).

Final soil samples were collected in November 2006, prior to contour ripping and the additional application of compost. Nitrate-N levels in all watersheds remained similar to the March 2006 measurements, and ranged from 1 to 3 ppm NO_3-N for samples at both sampling depths (Figs. 7A and 7B). Available P in C0 remained similar to those taken in March 2006 at 10 and 9 ppm P in the 0 – 5 cm and 5 – 15 cm soil depths, respectively. Available P in C1 watershed increased from earlier sample dates to 25 ppm P in the 0 – 5 cm sampling depth and slightly increased in the 5 – 15 soil depth to 10 ppm P. Samples collected from C2 watershed decreased in available P from 31 ppm P in March 2006 to 20 ppm P in November 2006 in the 0 – 5 cm depth and also had a slight decrease in the 5 – 15 depth to 10 ppm P (Fig. 7D).

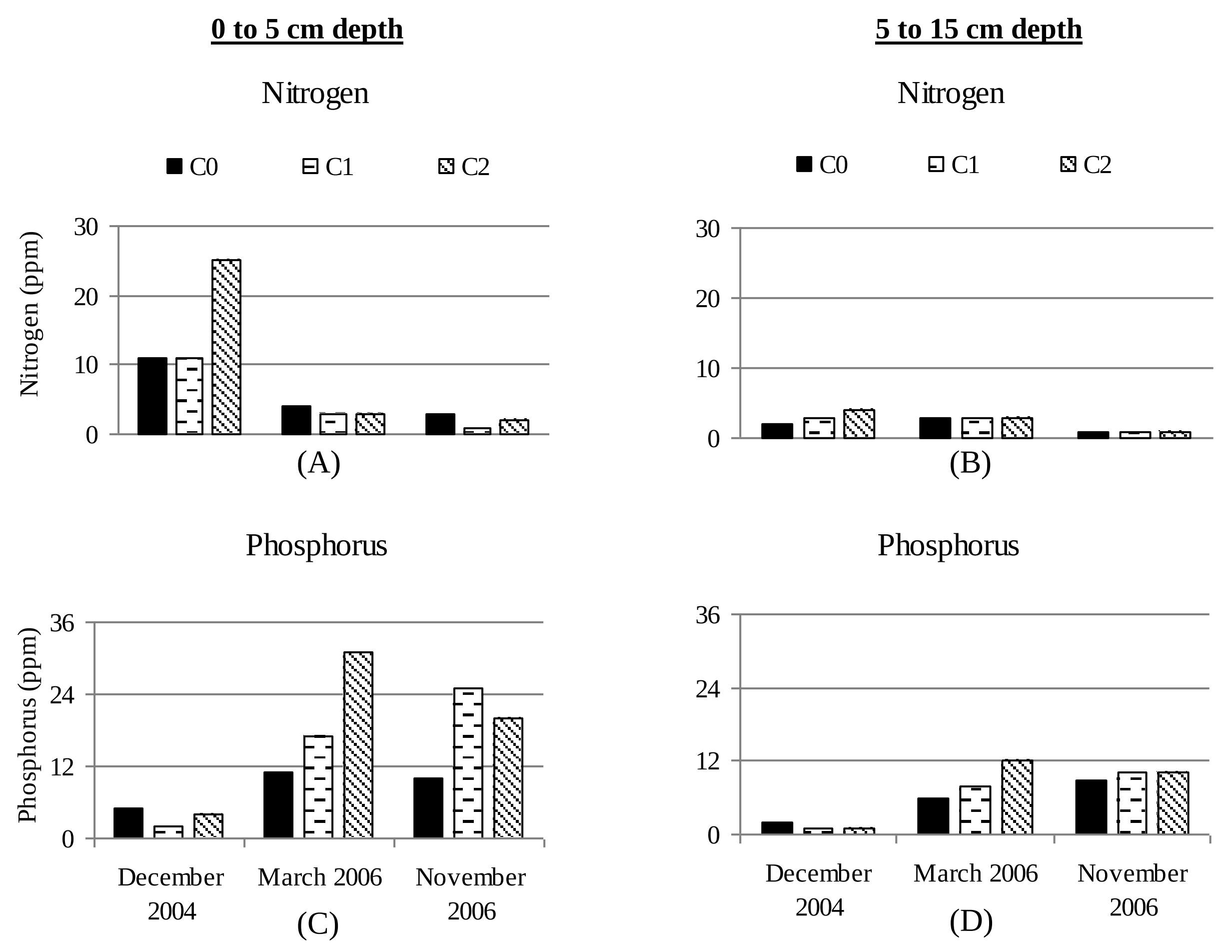

Figure 7 Analysis of A – B) nitrate-N and C – D) phosphorus levels in soil samples taken at two different sampling depths, A, C) 0 to 5 cm and B, D) 5 to 15 cm. Samples collected in December 2004, March 2006 and November 2006.

Stormwater Discharge

The precipitation pattern was very different between the pre- and post- rip periods. Total precipitation for the 22 month pre-rip period was 589.53 mm; while the 9 month post-rip period had 703.03 mm of precipitation (Tables 4 and 5). The precipitation between the two periods was significantly different ($p < 0.048$) as determined by Kruskal Wallis test. This precipitation difference essentially precludes any comparisons of treatments across the pre- and post-rip periods. Mean discharge from C0 watershed was 31.11 mm higher in the post-rip period than it was in the pre-rip period ($p < 0.008$), while the mean discharge from C1 and C2 was not significantly different between the two periods (Table 5).

There were 16 storm events during the pre rip period (January 2005 – October 2006) with a storm event precipitation mean of 36.85 mm in the 22 month period (Table 5). During the pre-rip period, discharge was not significantly different between any of the watersheds. Mean discharge was 14.38 mm, 17.11 mm and 18.01 mm for C0, C1 and C2, respectively (Table 5). In each storm event, for any given amount of precipitation, the three watersheds produced similar amounts of discharge (Fig. 8A). Discharge and runoff were not significantly different between the three watersheds during the pre-rip period (Table 5).

Table 4 Storm event precipitation, discharge and runoff from C0, C1 and C2 watersheds used to investigate the effects of contour ripping on stormwater runoff.

Date	C0 Precipitation	C0 Discharge	C1 Discharge	C2 Discharge	C0 Runoff†	C1 Runoff†	C2 Runoff†
	-- mm --	---------------- mm ----------------			----------- % ------------		
			*** Pre-Rip ***				
28-Jan-05	25.91	13.19	11.70	12.99	50.91	45.16	50.14
31-Jan-05	25.91	11.64	18.54	20.56	44.92	71.56	79.35
6-Feb-05	5.33	3.23	2.81	3.48	60.60	52.72	65.29
23-Feb-05	49.53	34.65	37.87	38.39	69.96	76.46	77.51
27-Feb-05	17.53	12.98	20.27	16.48	74.04	115.63	94.01
2-Mar-05	17.78	12.87	13.94	12.31	72.38	78.40	69.24
21-Mar-05	44.45	30.65	29.22	26.74	68.95	65.74	60.16
26-Mar-05	12.19	3.76	2.40	2.03	30.84	19.69	16.65
10-Apr-05	16.00	2.82	0.19	0.99	17.63	1.19	6.19
28-May-05	32.00	1.34	0.14	3.22	4.19	0.44	10.06
3-Jun-05	12.19	0.16	0.00	0.32	1.31	0.00	2.63
8-Aug-05	121.66	44.34	48.61	67.39	36.45	39.96	55.39
19-Mar-06	40.13	1.61	2.97	6.30	4.01	7.40	15.70
28-Mar-06	89.92	40.58	58.64	54.36	45.13	65.21	60.45
6-May-06	51.31	15.02	23.17	21.41	29.27	45.16	41.73
25-Oct-06	27.69	1.28	3.21	1.25	4.62	11.59	4.51
Pre-Rip Mean	36.85	14.38	17.11	18.01	38.45	43.52	44.31
Pre-Rip Total	589.53	230.12	273.68	288.22	---	---	---
			*** Post-Rip ***				
12-Mar-07	76.71	11.27	20.78	20.50	14.69	27.09	26.72
27-Mar-07	56.60	21.88	18.82	19.19	38.66	33.25	33.90
30-Mar-07	135.38	99.36	68.28	88.89	73.39	50.44	65.66
1-May-07	43.94	23.09	7.86	5.00	52.55	17.89	11.38
2-May-07	21.34	15.25	4.25	5.99	71.46	19.92	28.07
21-May-07	42.67	19.54	6.27	5.77	45.79	14.69	13.52
24-May-07	98.55	85.34	50.76	37.46	86.60	51.51	38.01
26-Jun-07	116.59	101.84	62.04	49.84	87.35	53.21	42.75
3-Jul-07	60.45	89.06	33.21	35.83	147.33	54.94	59.27
13-Jul-07	25.65	20.22	10.61	7.00	78.83	41.36	27.29
29-Jul-07	25.15	13.52	4.87	2.63	53.76	19.36	10.46
Post-Rip Mean	63.91	45.49	26.16	25.28	68.22	34.88	32.46
Post-Rip Total	703.03	500.37	287.75	278.10	---	---	---

† Precipitation from C0 micro-watershed used to calculate runoff.

Table 5 Pre-rip and post-rip period sums and event means (standard error) of precipitation, discharge and runoff of stormwater runoff events to evaluate the effect of contour ripping.

	C0		C1		C2	
	Total	Mean	Total	Mean	Total	Mean
Pre Rip						
Precipitation (mm)	-----------------------------		589.53	36.85 (7.69)	-------------------------	
Discharge (mm)	230.12	14.38 (3.74)	273.68	17.11 (4.59)	288.22	18.01 (5.01)
Runoff (%)†	---‡	38.45 (6.63)	---	43.52 (8.61)	---	44.31 (7.66)
Post Rip						
Precipitation (mm)	-----------------------------		703.03	63.91 (11.65)	-------------------------	
Discharge (mm)	500.37	45.49 (11.69)	287.75	26.16 (7.20)	278.10	25.28 (7.97)
Runoff (%)†	---	68.22 (10.36)	---	34.88 (4.79)	---	32.46 (5.50)

† Runoff percent calculated with C0 precipitation
‡ Period sum for runoff (%) is not applicable

The post-rip period (November 2006 – July 2007) had eleven storm events in nine months; mean storm event precipitation was 63.91 mm. In the post-rip period, discharge and runoff from C1 and C2 were significantly different when compared to the control (C0) (Table 5). The watershed that was contour ripped only (C1) had a storm event mean discharge of 19.33 mm less than the control plot ($p < 0.006$). The watershed that received an additional composted dairy manure application in conjunction with contour ripping (C2) had an average of 20.21 mm of discharge less than the control watershed during the post-rip period ($p < 0.008$) in a storm event. There was no significant difference in discharge of the two ripped watersheds ($p < 0.374$).

While the two contour ripped watersheds continued to have approximately the same amount of discharge for any given amount of precipitation, the untreated control nearly always had higher discharge amounts (Fig. 8B)

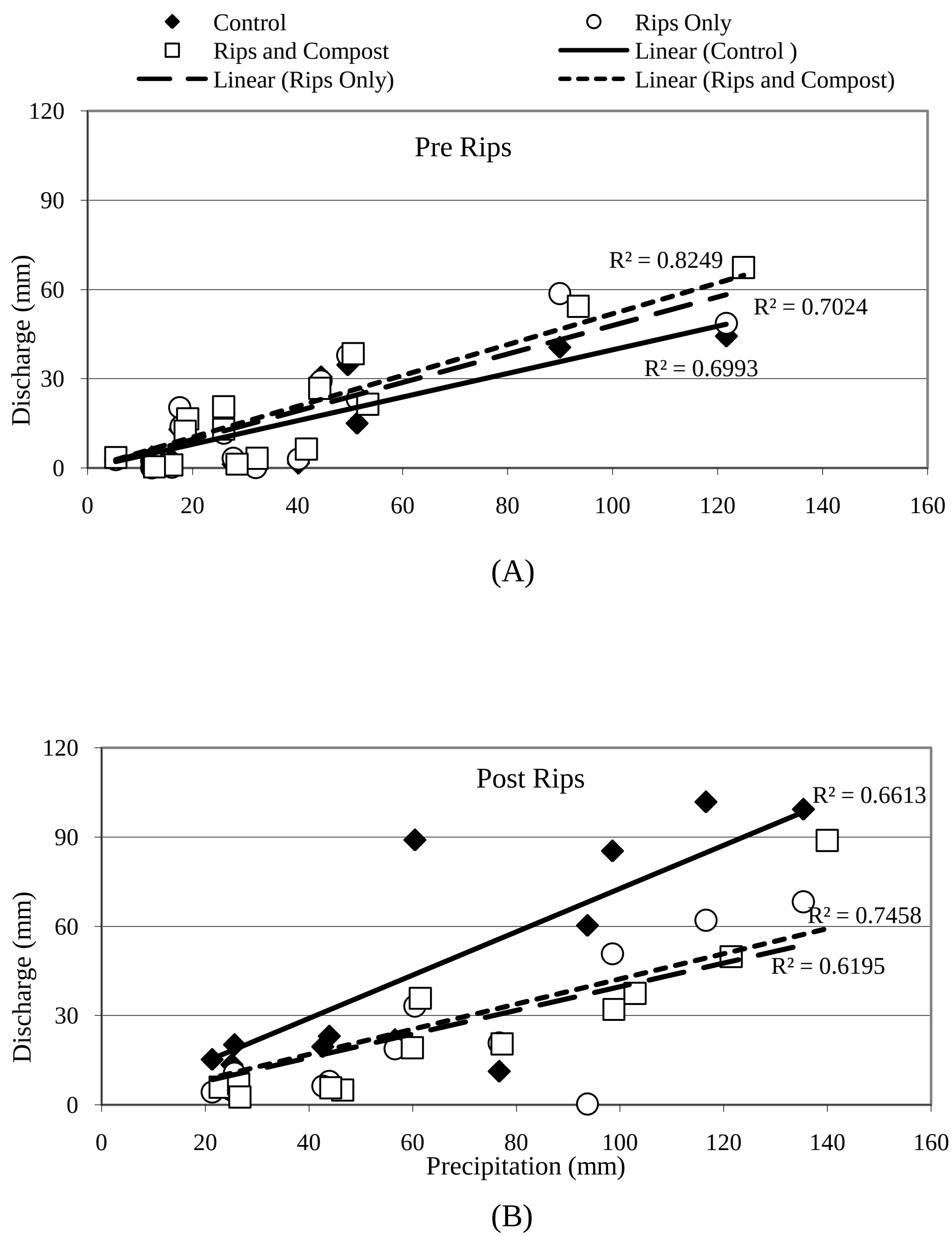

Figure 8 Storm event precipitation to predict discharge in A) pre-rip and, B) post-rip periods.

Stormwater Quality

The first year immediately following compost application (2005), C0 (control) watershed had lower NO_3 and SRP loads than both compost treatments (Table 6). C0 had a mean NO_3 load of 0.02 kg in 2005 and no measurable loss of SRP, while C1 (28 m^3 ha^{-1} application) had a mean load of 0.32 kg NO_3, on average, 0.29 kg more than the control ($p < 0.017$) and a mean SRP load of 0.13 kg ($p < 0.007$). Watershed C2 (57 m^3 ha^{-1} application) had a mean load of 0.37 kg NO_3, on average 0.35 kg more than the mean load of the Control ($p < 0.028$) and 0.05 kg NO_3 more than the mean load of C1 ($p < 0.028$). C2 had a mean SRP loss of 0.18 kg, with a mean difference of 0.18 and 0.05 kg SRP from C0 ($p < 0.008$) and C1 ($p < 0.027$), respectively (Table 6).

There were 15 storm events in 2005. C0 had an annual (total) load of 0.33 NO_3 kg yr^{-1} while C1 and C2 had an annual load of 2.84 and 3.72 NO_3 kg yr^{-1}, respectively in 2005 (Table 6 and 7). C0 had no detectable SRP loss during 2005; however C1 and C2 had annual loads of 1.14 and 1.75 kg yr^{-1} of SRP, respectively (Tables 6 and 7).

The study year 2006 was a drought year, with only six storm events. One year post initial application, there were no significant differences between treatments in NO_3 load and concentration and SRP load and concentration. The mean NO_3 concentration ranged from 0.13 to 0.44 mg l^{-1} for all watersheds (Table 6), while SRP mean concentrations ranged from 0.00 to 1.68 mg l^{-1} (Table 6), all much lower than they had been in 2005. Mean storm event loads also decreased substantially for both NO_3 and SRP from 2005.

Table 6 Watershed total and mean (standard error) of NO_3 and SRP Load and mean (standard error) of NO_3 and SRP Concentration in 2005, 2006, 2007 and total study period.

	C0		C1		C2		C0	C1	C2
	Load						Concentration		
	Total	Mean	Total	Mean	Total	Mean	Mean	Mean	Mean
	kg						$mg\ l^{-1}$		
NO_3									
2005	0.33	0.02 (0.01)	2.84	0.32 (0.18)	3.72	0.37 (0.23)	1.07 (0.14)	11.10 (6.47)	8.61 (5.46)
2006	0.12	0.02 (0.02)	0.05	0.01 (0.01)	0.00	0.00 (0.00)	0.44 (0.16)	0.13 (0.06)	0.24 (0.15)
2007	0.16	0.01 (0.01)	0.11	0.01 (0.01)	0.09	0.01 (0.00)	0.21 (0.10)	0.15 (0.13)	0.13 (0.08)
2005 - 2007	0.61	0.02 (0.00)	3.00	0.11 (0.06)	3.81	0.14 (0.09)	0.60 (0.10)	3.80 (2.31)	3.18 (2.04)
SRP									
2005	0.00	0.00 (0.00)	1.14	0.13 (0.03)	1.75	0.18 (0.05)	0.00 (0.00)	3.85 (1.06)	4.08 (0.93)
2006	0.00	0.00 (0.00)	0.15	0.04 (0.02)	0.22	0.04 (0.04)	0.00 (0.00)	0.76 (0.13)	1.68 (0.18)
2007	0.00	0.00 (0.00)	0.34	0.02 (0.01)	0.13	0.01 (0.01)	0.00 (0.00)	0.66 (0.17)	0.21 (0.08)
2005 - 2007	0.00	0.00 (0.00)	1.63	0.06 (0.01)	2.10	0.08 (0.02)	0.00 (0.00)	1.74 (0.46)	1.86 (0.47)

C0 had an annual load of 0.12 kg of NO_3, while C1 and C2 had annual loads of 0.05 and 0.00 kg NO_3, respectively (Tables 6 and 7). There was no measurable SRP loss from C0 during 2006. C1 and C2 had annual loads of 0.15 kg and 0.22 kg of SRP, respectively (Table 6). SRP concentration differences between the two compost treated plots and the control where just out of the range of significance ($p < 0.068$).

In November 2006, C1 and C2 both received a contour ripping treatment and C2 had an additional 28 m^3 ha^{-1} of compost applied. There were no storm events following treatments until January 2007. There were 18 storm events in 2007, with most of the events occurring in the spring. In 2007, C1 had an annual load of 0.16 kg of NO_3 and no measurable loss of SRP. C1 had an annual load of 0.11 kg of NO_3 and 0.34 kg SRP, while C2 had 0.09 kg of NO_3 and 0.13 kg of SRP in annual load (Table 6).

In 2007, two years post initial application, there continued to be no significant differences in the mean NO_3 loads and concentrations between the three watersheds. NO_3 mean loads from the watersheds ranged from 0.01 to 0.09 kg (Table 6). Mean event concentrations were equal to or less than 0.21 mg l^{-1} of NO_3 for all three watersheds. C0 continued to have no measurable loss of SRP. C1 had a mean SRP load of 0.02 kg and was statistically different from the mean SRP load of C0 ($p < 0.008$). C2 had a mean load of 0.01 kg and was also significantly different from C0 ($p < 0.008$). The difference between C1 and C2 was just out of the significance range for mean SRP loads ($p < 0.056$).

Table 7 Storm event discharge, NO3 and SRP load and concentration from C0, C1 and C2 in 2005, 2006 and 2007.

Event Date	C0	C1	C2	C0	C1	C2	C0	C1	C2	C0	C1	C2	C0	C1	C2
	Discharge			NO_3 Load			SRP Load			NO_3 Concentration			SRP Concentration		
	-------m^3-------			------------------- kg		---------------------				----------------------mg		L^{-1}----------------------			
** 2005 **															
1/27/2005	36.37	27.64	NC†	0.04	1.70	NC	0.00	0.31	NC	1.20	61.67	NC	0.00	11.36	NC
1/30/2005	2.77	NE‡	NC	0.00	NE	NC	0.00	NE	NC	1.08	NE	NC	0.00	NE	NC
1/31/2005	3.26	8.15	NC	0.00	0.11	NC	0.00	0.04	NC	0.87	13.22	NC	0.00	5.31	NC
2/1/2005	5.58	20.14	NC	0.00	0.14	NC	0.00	0.10	NC	0.87	7.00	NC	0.00	4.82	NC
2/6/2005	5.26	NE	NC	0.01	NE	NC	0.00	NE	NC	2.00	NE	NC	0.00	NE	NC
2/23/2005	31.75	32.21	42.15	0.03	0.21	2.40	0.00	0.09	0.49	0.89	6.49	56.94	0.00	2.77	11.54
2/24/2005	64.29	63.68	64.71	0.07	0.42	0.59	0.00	0.12	0.33	1.07	6.52	9.12	0.00	1.92	5.17
2/26/2005	24.80	43.17	42.12	0.00	0.00	0.27	0.00	0.14	0.23	0.00	0.00	6.40	0.00	3.30	5.49
3/2/2005	32.56	35.45	35.15	0.03	0.11	0.23	0.00	0.10	0.15	0.83	3.24	6.52	0.00	2.94	4.20
3/21/2005	91.08	86.07	80.48	0.10	0.15	0.17	0.00	0.14	0.20	1.12	1.76	2.07	0.00	1.58	2.51
3/26/2005	6.30	NE	2.60	0.01	NE	0.00	0.00	NE	0.01	1.14	NE	1.20	0.00	NE	3.66
4/10/2005	7.96	NE	2.62	0.01	NE	0.00	0.00	NE	0.01	1.87	NE	1.73	0.00	NE	2.63
5/28/2005	3.75	NE	9.71	0.00	NE	0.01	0.00	NE	0.02	1.22	NE	0.91	0.00	NE	2.27
6/3/2005	0.19	NE	0.27	0.00	NE	0.00	0.00	NE	0.00	1.70	NE	0.93	0.00	NE	1.86
8/9/2005	133.68	146.80	205.60	0.03	0.00	0.05	0.00	0.10	0.31	0.22	0.00	0.23	0.00	0.67	1.49
Annual Load	449.60	463.31	485.41	0.33	2.84	3.72	0.00	1.14	1.75	---	---	---	---	---	---
Annual Mean	29.97	51.48	48.54	0.02	0.32	0.37	0.00	0.13	0.18	1.07	11.10	8.61	0.00	3.85	4.08
** 2006 **															
3/19/2006	4.33	8.56	18.66	0.00	0.00	0.00	0.00	0.01	0.00	0.81	0.06	0.72	0.00	0.88	1.75
3/28/2006	121.41	177.07	164.31	0.09	0.03	0.00	0.00	0.09	0.19	0.12	0.18	0.00	0.00	0.50	1.15
4/29/2006	NE	NE	9.70	NE	NE	0.00	NE	NE	0.02	NE	NE	0.00	NE	NE	2.08
5/6/2006	43.13	69.09	NE	0.03	0.02	NE	0.00	0.04	NE	0.78	0.28	NE	0.00	0.61	NE
10/10/2006	0.34	NE	2.70	0.00	NE	0.00	0.00	NE	0.01	0.44	NE	0.48	0.00	NE	2.03
10/25/2006	3.72	9.11	3.51	0.00	0.00	0.00	0.00	0.01	0.00	0.03	0.00	0.00	0.00	1.05	1.41
Annual Load	172.93	263.83	198.88	0.12	0.05	0.00	0.00	0.15	0.22	---	---	---	---	---	---
Annual Mean	34.59	65.96	39.78	0.02	0.01	0.00	0.00	0.04	0.04	0.44	0.13	0.24	0.00	0.76	1.68

† No compost applied

‡ No event or insufficient discharge to collect sample

Table 7 Continued.

Event Date	C0	C1	C2	C0	C1	C2	C0	C1	C2	C0	C1	C2	C0	C1	C2
	Discharge			NO_3 Load			SRP Load			NO_3 Concentration			SRP Concentration		
	-------m^3-------			------------------- kg ---------------------						-----------------------mg L^{-1}----------------------					
							** 2007 **								
3/11/2007	33.20	59.00	61.10	0.03	0.01	0.05	0.00	0.08	0.06	0.82	0.25	0.89	0.00	1.35	1.05
3/26/2007	56.72	54.12	47.89	0.00	0.10	0.03	0.00	0.00	0.00	0.06	1.81	0.60	0.00	0.00	0.00
3/29/2007	108.40	67.20	90.80	0.01	0.00	0.00	0.00	0.00	0.05	0.07	0.00	0.01	0.00	0.41	0.53
3/30/2007	182.99	132.42	173.80	0.01	0.00	0.00	0.00	0.04	0.02	0.04	0.00	0.00	0.00	0.36	0.14
5/1/2007	68.71	19.79	13.51	0.01	0.00	0.00	0.00	0.01	0.00	0.12	0.00	0.00	0.00	0.64	0.16
5/2/2007	39.20	7.67	10.20	0.01	0.00	0.00	0.00	0.01	0.00	0.29	0.00	0.00	0.00	0.71	0.15
5/9/2007	7.30	NE	NE	0.00	NE	NE	0.00	NE	NE	0.27	NE	NE	0.00	NE	NE
5/22/2007	58.42	16.54	15.75	0.09	0.00	0.00	0.00	0.01	0.00	1.55	0.00	0.00	0.00	0.88	0.14
5/24/2007	74.17	45.93	27.27	0.00	0.00	0.00	0.00	0.12	0.00	0.01	0.00	0.00	0.00	2.54	0.00
5/25/2007	57.10	66.10	44.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.24	0.00
6/26/2007	67.80	34.79	17.41	0.00	0.00	0.00	0.00	0.03	0.00	0.07	0.00	0.00	0.00	0.75	0.25
6/27/2007	35.94	15.10	11.66	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.50	0.13
6/28/2007	19.08	86.37	62.65	0.00	NA	NA	0.00	NA	NA	0.00	NA	NA	0.00	NA	NA
6/30/2007	63.59	51.49	41.51	NA	0.00	0.01	NA	0.01	0.00	NA	0.00	0.19	NA	0.29	0.00
7/3/2007	78.00	72.38	67.81	0.00	0.00	NA	0.00	0.02	NA	0.00	0.00	NA	0.00	0.31	NA
7/5/2007	4.19	3.43	2.09	NA	0.00	0.00	NA	0.00	0.00	NA	0.00	0.00	NA	0.26	0.22
7/7/2007	11.66	NE	NE	0.00	NE	NE	0.00	NE	NE	0.00	NE	NE	0.00	NE	NE
7/8/2007	3.68	NE	NE	0.00	NE	NE	0.00	NE	NE	0.00	NE	NE	0.00	NE	NE
Annual Load	970.15	732.33	687.45	0.16	0.11	0.09	0.00	0.34	0.13	---	---	---	---	---	---
Annual Mean	53.90	48.82	45.83	0.01	0.01	0.01	0.00	0.02	0.01	0.21	0.15	0.13	0.00	0.66	0.21

† No compost applied

‡ No event or insufficient discharge to collect sample

The differences that existed among treatments when analyzed by individual years were lessened or obscured when analyzing the results as a whole for the entire study period (2005 – 2007) (Table 6). The only significant difference in NO_3 concentration was between C1 and C2; C1 had a mean event concentration of 3.80 mg $l^{-1,}$ while C2 was 3.18 mg l^{-1} (p < 0.025 for the entire study period (Table 6). There were no significant differences in NO_3 loads among any of the watersheds. SRP loss from the control was significantly different in both C1 ($p < 0.000$) and C2 ($p < 0.001$). SRP loss was not significantly different between the two treated watersheds. This trend continued in the SRP mean concentration, C1 and C2 were not different ($p < 0.357$), but both differed from C0 ($p < 0.000$ and $p < 0.000$) (Table 6).

There were 43 storm events monitored during the entire study period. Total load for the entire study period (2005 – 2007) for C0 (control) was 0.65 kg of NO_3 and no measurable SRP loss (Tables 6 and 7). C1 had a total load of 3.01 kg of NO_3 and 1.67 kg of SRP and C2 had a total load of 3.81 kg and 2.15 kg of NO_3 and SRP, respectively.

The greatest differences in water quality were seen immediately after compost application in 2005 (Figs. 9 – 12). The first storm event came one day after compost application on C1. There were eight storm events from 27 January 2005 to 26 February 2005, the first month after application. During this time, the total load was 2.58 kg NO_3 and 0.80 kg of SRP for C1 (Table 7). Eighty-six percent of the total NO_3 load and 48% of the total SRP load from C1 for the entire study period was removed in the first eight events.

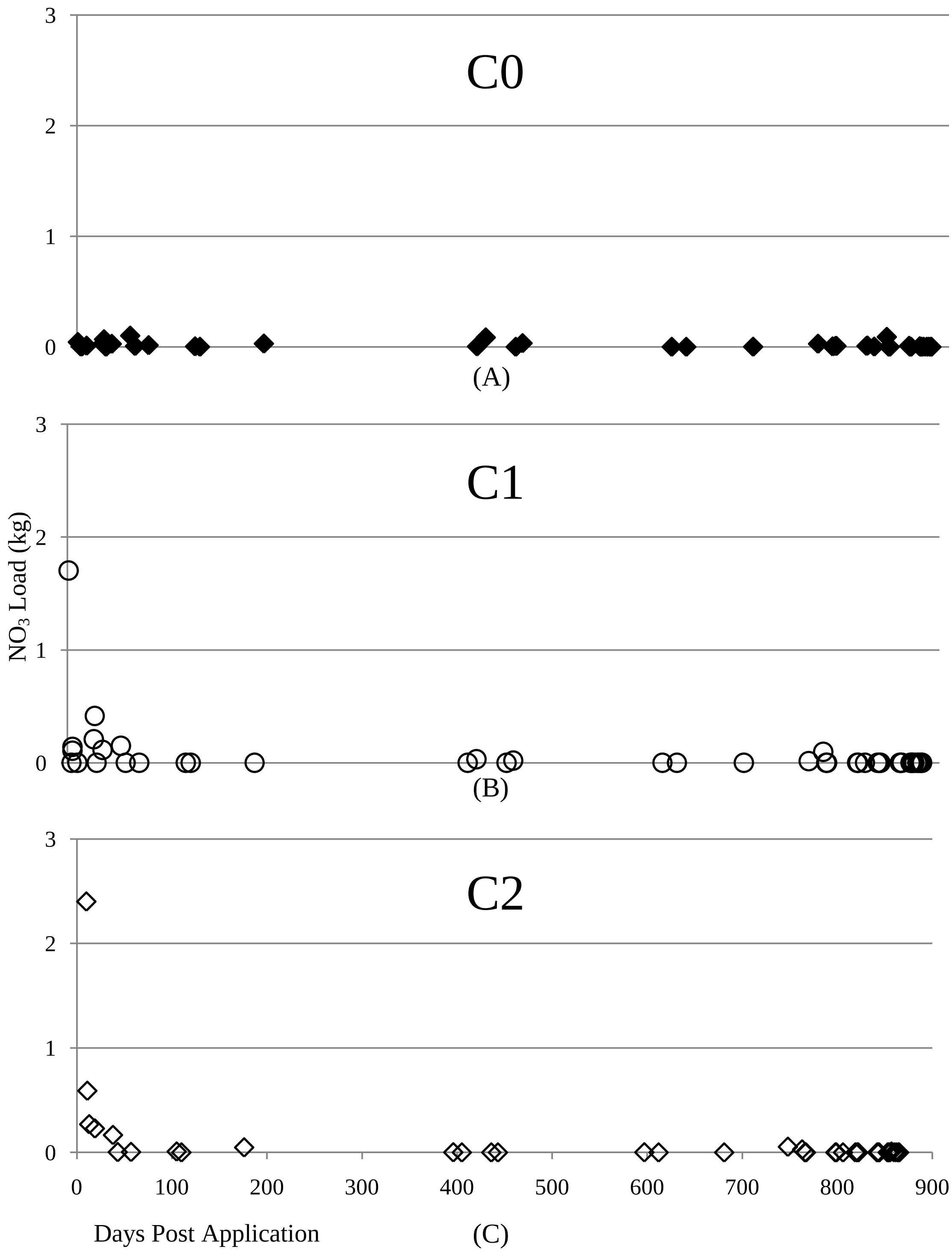

Figure 9 NO_3 storm event loss (kg) for A) C0, control, B) C1, 28 m^3 ha^{-1} and C) C2, 57 m^3 ha^{-1} over number of days after compost application. C0 and C1 begin on 26 January 2005 and C2 begins on 13 February 2005.

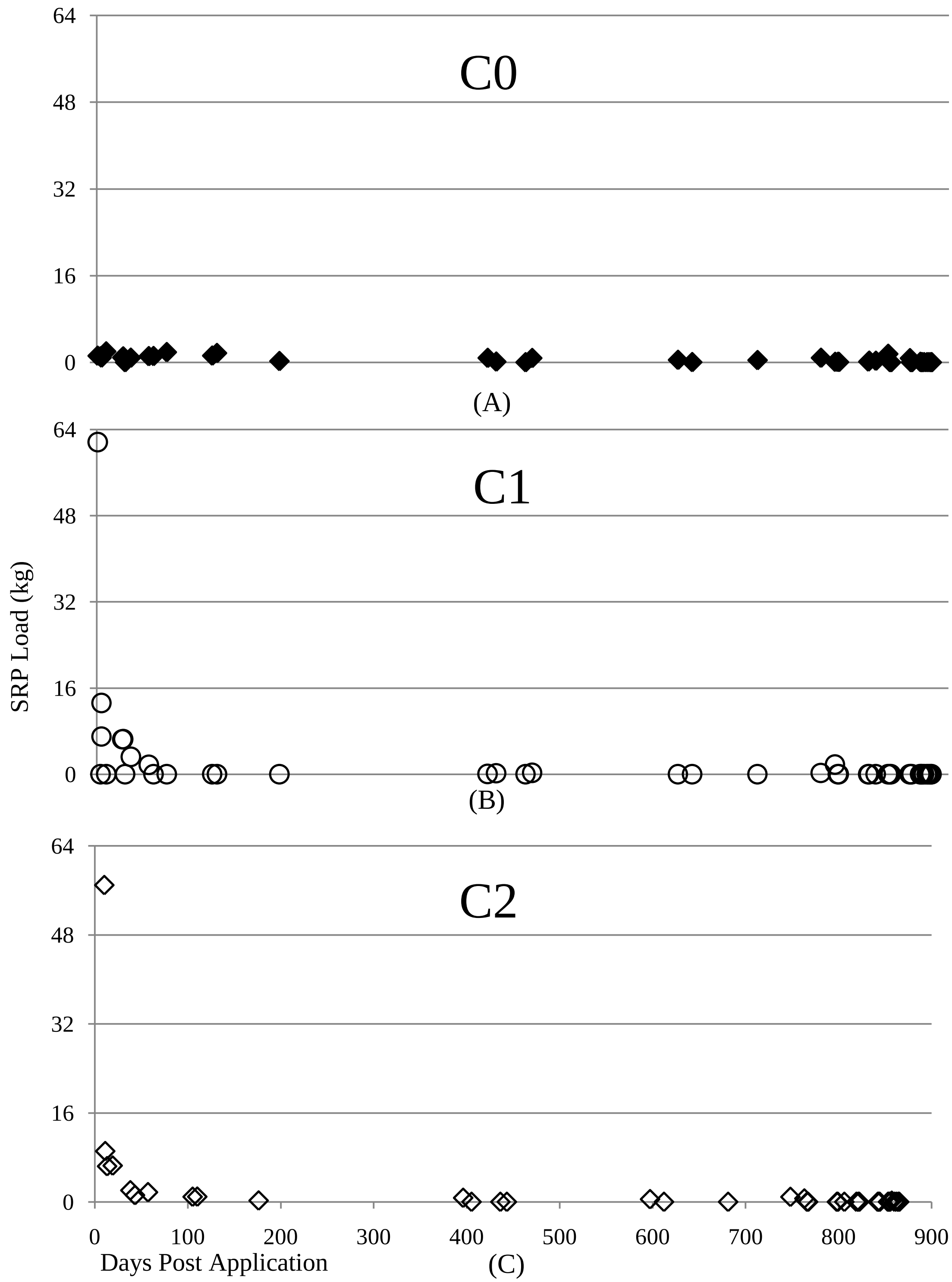

Figure 10 SRP storm event loss (kg) for A) C0, control, B) C1, 28 m^3 ha^{-1} and C) C2, 57 m^3 ha^{-1} over number of days after compost application. C0 and C1 begin on 26 January 2005 and C2 begins on 13 February 2005.

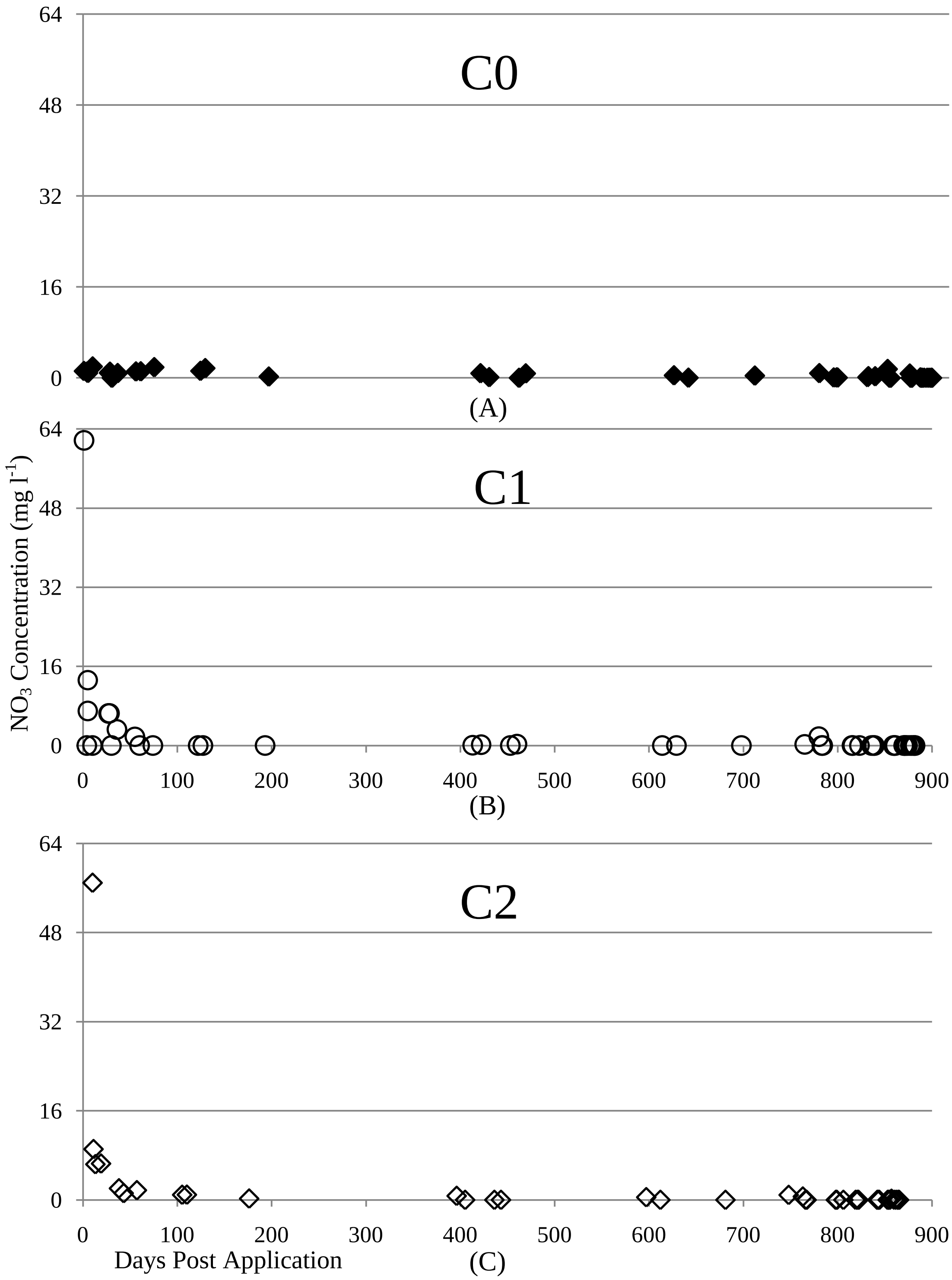

Figure 11 NO_3 storm event concentration (mg l^{-1}) for A) C0, control, B) C1, 28 m^3 ha^{-1} and C) C2, 57 m^3 ha-[1]over number of days after compost application. C0 and C1 begin on 26 January 2005 and C2 begins on 13 February 2005.

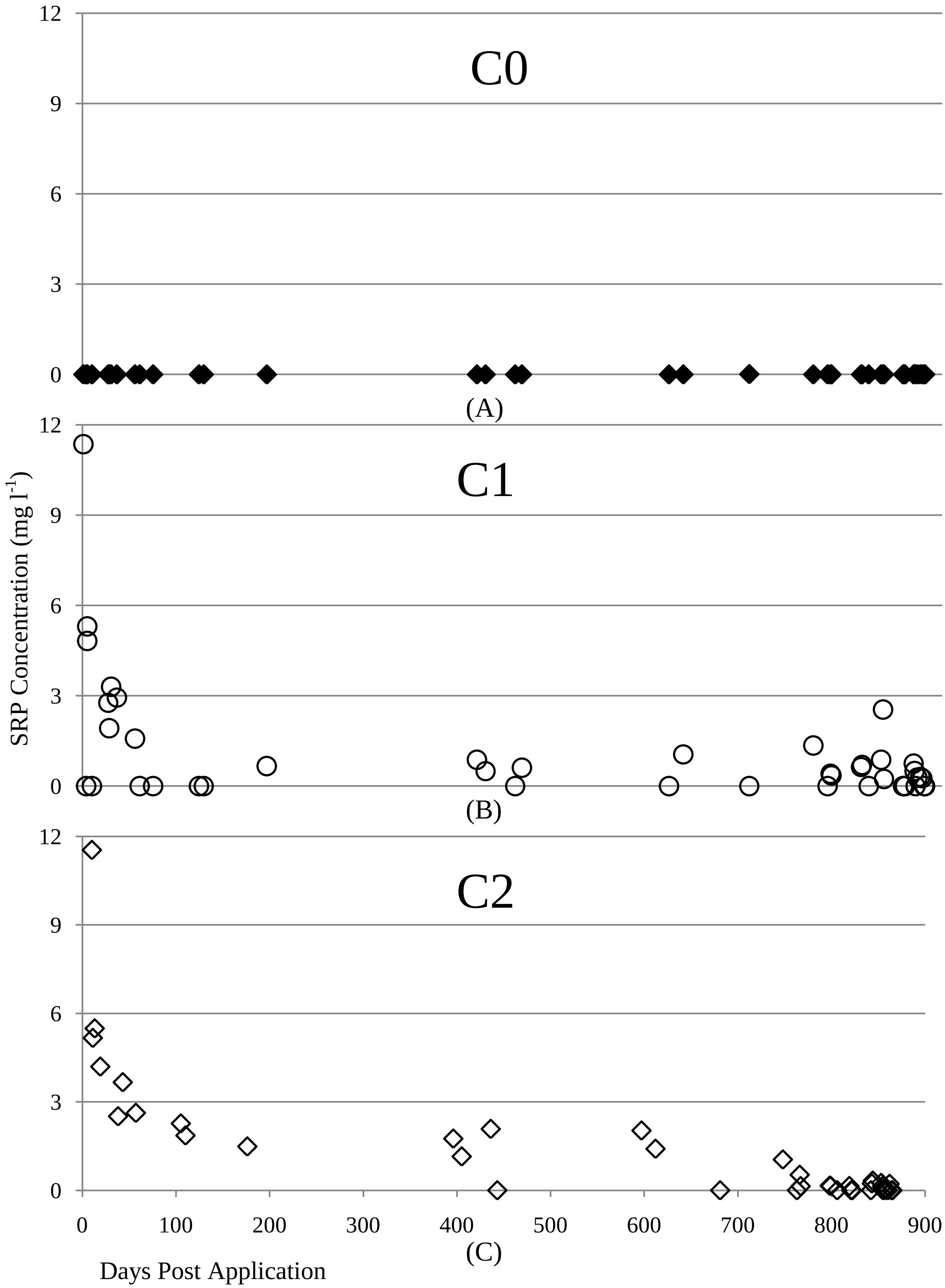

Figure 12 SRP storm event concentration (mg l^{-1}) for A) C0, control, B) C1, 28 m^3 ha^{-1} and C) C2, 57 m^3 ha^{-1}over number of days after compost application. C0 and C1 begin on 26 January 2005 and C2 begins on 13 February 2005.

Although storm events started almost immediately after application on C1, the first storm event on C2 after compost application was ten days from date of application. Three storm events occurred between date of application and 26 February 2005. In the first two weeks, C2 had a total load of 3.26 kg of NO_3 and 1.05 kg of SRP or 86% and 50% of total NO_3 and SRP loss for the entire study period, respectively. Within the first month after compost application on C2, 3.66 kg of NO_3 and 1.40 kg of SRP had been removed, or 96% and 67% of the total load for the study period (Table 7). NO_3 and SRP storm loads decreased as the number of days post initial application increased (Figs. 9 and 10).

This is very similar to what studies conducted on cropland found. Concentrations of NO_3 and SRP are inversely related to the number of days after compost application (Figs. 11 and 12). In C1, NO_3 and SRP concentration dropped from 61.67 to 1.76 mg l^{-1} and 11.36 to 1.58 mg l^{-1}, respectively, within two months and decreased to below 1.0 mg l^{-1} NO_3 and 0.67 mg l^{-1} after eight months (Figs. 11 and 12). In C2, NO_3 and SRP concentrations decreased from 56.94 mg l^{-1} to 0.91 mg l^{-1} and 11.54 mg l^{-1} to 2.63 mg l^{-1}, respectively, two months post application.

The highest concentrations of NO_3 and SRP from both treated plots occurred in the first storm events after compost application. C2 had a lower initial NO_3 concentration (56.94 mg $^{-1}$) than C2 (61.67 mg l^{-1}), because there was a longer lag time between application and the first storm event (Table 6).

DISCUSSION

Soils

The initial high NO_3-N concentration in the soil sample from C2 is not related to the compost application treatments. It may, however, be explained by the presence of cattle and other wildlife in the area. Since the samples from each watershed was a composite of six random samples, a portion of the sample from C2 in December 2004 may have been collected where a cow or other wildlife had recently urinated and thus had a higher NO_3-N concentration. It is not possible to prove or disprove this theory, and is only offered as a possible explanation. The spike in NO_3-N was only seen in the upper 0 – 5 cm of the soil profile, and was similar to NO_3-N concentrations in C0 and C1 in subsequent sampling dates. Nitrate-N concentrations decreased in all watersheds at both sampling depths after the December 2004 samples. It does not appear that compost addition at rates of 28 and 57 mg ha^{-1} had an effect on soil NO_3-N concentrations.

Plant available phosphorus was low in the December 2004 samples, ranging from 1 to 5 ppm P. This is somewhat expected since the plant available phosphorus supply is typically low in soils and the phosphates that are in the soil are not readily available for plant use. Also, in alkaline soils, low-solubility calcium triphosphate is formed and soluble phosphate ions also adsorb on solid calcium carbonate surfaces (Miller and Donahue 1995). The soils found in the study watersheds are high in calcium carbonate. Both watersheds that received compost application had higher available P than the untreated watershed, particularly in the samples collected at 0 – 5 cm depth. This suggests that compost application increased the amount of available P in the soil.

Although P concentrations in subsequent sample dates were higher than the initial samples, they were still relatively low.

Stormwater Discharge

The three watersheds all behaved very similar hydrologically during the pre-rip period, even though two of the watersheds received varying rates of compost application. During that period, there was no discernable trend in discharge amounts; there was not one watershed that consistently had higher or lower discharge amounts prior to contour ripping and there was no significant difference in discharge and runoff between watersheds.

This changed after the contour ripping treatments were applied. With the exception of the first event after (three months post ripping), the untreated C0 watershed consistently had higher amounts of discharge during a storm during storm events. The two ripped watersheds continued to behave similarly. In 55% of storm events, C2 watershed (contour ripping and additional compost application) had the lowest mean discharge among all three watersheds. The watershed that received contour ripping without an additional compost application, C1, had the lowest amount of discharge in 36% of the storm events. The two contour ripped watersheds consistently had less discharge than the control watershed; however, as the time between storm events became shorter, the discharge gap between C0 and the two ripped plots grew wider. The ability to decrease discharge by contour ripping seemed to increase during extended rainy periods.

In the post rip period, C1 and C2 had 74% and 80% less discharge than the control watershed, respectively. While this is a significant decrease from the control plot, these results are probably magnified by the small scale of the watersheds. Previous work conducted on Fort Hood measured the effectiveness of contour ripping in conjunction with the installation of gully plugs (check dams) in the vast network of gullies within the Shoal Creek watershed (approximately 2000 ha). Discharge was measured at the outflow point of Shoal creek. Twenty-nine pre-implementation and 31 post implementation storm events were monitored over a 10 year period. Mean runoff from the watershed was reduced by 61% in the post period when compared to the pre period. Since the contour ripping was implemented at the same time as the gully plugs, it is not possible to determine the effects from the individual treatments (Wolfe et al. 2008). When making comparisons between that study and the work presented here, it is important to acknowledge that contour ripping alone did not cause the 61% reduction in discharge alone. The large watershed study emphasizes the importance of recognizing the role that spatial scale plays in this edge of field runoff study. These small scale watersheds had reductions in discharge of 74 and 80% with contour ripping alone. Although it is a significant reduction, in large watersheds these values will not be achieved with contour ripping alone, because of other landscape processes at work.

Stormwater Quality

Since NO_3 is the form of N that is most readily leached from the soil, leaching losses are increased as the amount of percolating water is increased in the soil or when there is little or no growing cover crop to absorb the nitrates. In cropping systems, NO_3 losses from soils with an actively growing crop are typically only a few kg a year, with the exception being the recent addition of large amounts of fertilizers (Miller and Donahue 1995). Stormwater quality samples illustrated this trend. With the exception of the first two storm events from C1 and the first storm event from C2, all NO_3 concentrations were low and below EPA's requirement of NO3 concentration less than 10 mg l^{-1}. Forty four percent and 60% of the storm events in 2005 from C1 and C2 were below TCEQ's more stringent standard of 2.76 mg l^{-1}. All subsequent storm events in 2006 an 2007 were well below both EPA and TCEQ's standard. Unlike SRP concentrations, the control watershed, C0, had small losses of NO_3 throughout the study period, but all concentrations were much lower than any of the regulatory standards. This demonstrates that there was a background NO_3 loss even without compost application. While the addition of compost did effect the NO_3 concentrations and loading, the effect only lasted for one year after treatment. There was no difference in NO_3 concentration during 2006 and 2007.

The behavior of inorganic P in soils can be described by adsorption – desorption reactions. Additions of inorganic P initially sorb weakly or strongly to variable charge surfaces associated with calcium in calcareous soils. After initial adsorption, P can become less labile, possibly through diffusive penetration (adsorption) of adsorped phosphate ions into soil components. This adsorption makes the P less available to plants, but it is not permanently unavailable to plants (Evans and Johnston 2004). Although C1 did not receive an additional compost application in November 2006, the SRP concentration was significantly different from both C0 and C2. This suggests that the contour ripping and subsequent disaggregation caused some of the previously "fixed" phosphorus to become more labile and available for loss in the form of SRP.

Both of the compost application rates caused SRP concentrations to exceed both EPA and TCEQ's standards in most storm events. The SRP concentration in C1 and C2 exceeds both agencies' standards for all storm events in 2005. In 2006, C1 and C2 continued to exceed the limits of the EPA guidelines for SRP in all storm events. Even with TCEQ's more lenient limits, C2 always exceeded the SRP limits, as did C1 with the exception of one event that was below the limit.

In 2007, 53% of events that produced enough discharge for sampling on C1 were below TCEQ's standard for SRP; however EPA's guidelines were exceeded in all but one event. SRP concentrations from C2 watershed were below TCEQ's guidelines 77% of the storm events, of those events; four had no measurable SRP concentration and were below EPA standards.

Even though some of the storm events exceeded TCEQ and EPA guidelines, comparison of these edge-of-field studies must be made with the understanding that the regulatory requirements were developed for instream flows. Therefore, direct comparisons cannot be made. The nutrient concentrations from these 0.30 ha watersheds are magnified by the small spatial scale. In larger watersheds, these values would be lessened by natural landscape processes that are not found in the small homogenous plots.

It does, however, demonstrate that once compost is applied, both NO_3 and SRP concentrations will spike if followed immediately by storm events. After the first few storm events, NO_3 concentrations decrease to baseline (control) levels. SRP remains slightly elevated three years after initial application, particularly if the soil is subjected to disturbance.

CONCLUSIONS

One of Fort Hood's environmental objectives is to reduce the erosion from training lands. In effort to accomplish that goal, Fort Hood is evaluating two methods, compost application to increase vegetation and contour ripping to decrease discharge; and in turn decrease erosion.

This study evaluated the effects of two compost application rates on stormwater discharge and quality. Changes in vegetation cover and composition in relation to application rates was not analyzed in this paper, so it is not possible to make statements about that relationship. However, there was no significant difference in discharge among all watersheds after the initial compost application. This suggests that, at least in the short-term, neither one of the compost application rates evaluated affected the vegetation in the watersheds enough to alter discharge.

Loss of nutrients after compost application is a concern for land managers. The compost application did cause the stormwater quality from the two treated watersheds to be significantly different from the control for all measured parameters immediately after application. Although C2 watershed received double the rate that was applied to C1, the differences in NO_3 and SRP were not linear. Both watersheds had high NO_3 and SRP loads during the first year post application with extremely high loads and concentrations in the first month after application. While C2 did have higher concentrations and loads, they were not double those losses exhibited by C1. This is possibly influenced by the differences in the timing of compost application in relation to the first storm event between C1 and C2. There was not a similar spike in NO_3 and SRP loads and concentrations on C2 after the second compost application in November 2006 since the first measurable storm event did not occur until four months post application. This emphasizes the influence of compost application in relation to storm events and the non-linearity of water quality results between the two application rates. Both C1 and C2 had elevated SPR concentrations after the contour ripping treatments were applied. This also suggests that the “fixed” P may become labile after disturbance in areas previously treated with compost. This may be a concern because of the inevitable disturbances caused by military training.

Contour ripping reduced discharge 74 and 80% on C1 and C2, respectively, when compared to the control watershed. Any practice that reduces the stormwater overland flow and subsequent discharge will reduce erosion, since water mediated erosion is mediated by overland flow. It is possible that the initial compost and seed applications played a role in the reduction of discharge at this point in the study. Native grass species can sometimes take up to two years to become established after planting. The grasses may have established enough to thrive during the third growing season to have an effect on discharge. A vegetation inventory was conducted by Texas Water Resources Institute (TWRI) throughout the study period. Further analysis of that dataset may help determine if the seed and compost application increased or underwent a change in vegetation composition and thus influenced the discharge in the post-rip period.

While compost application may possibly affect vegetation and subsequently erosion, the effects are not immediate. Alternatively, contour ripping immediately reduces discharge and appears to be the more logical choice when designing conservation practices to reduce erosion on Fort Hood.

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